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(54) **SIMPLIFIED INK JET HEAD**

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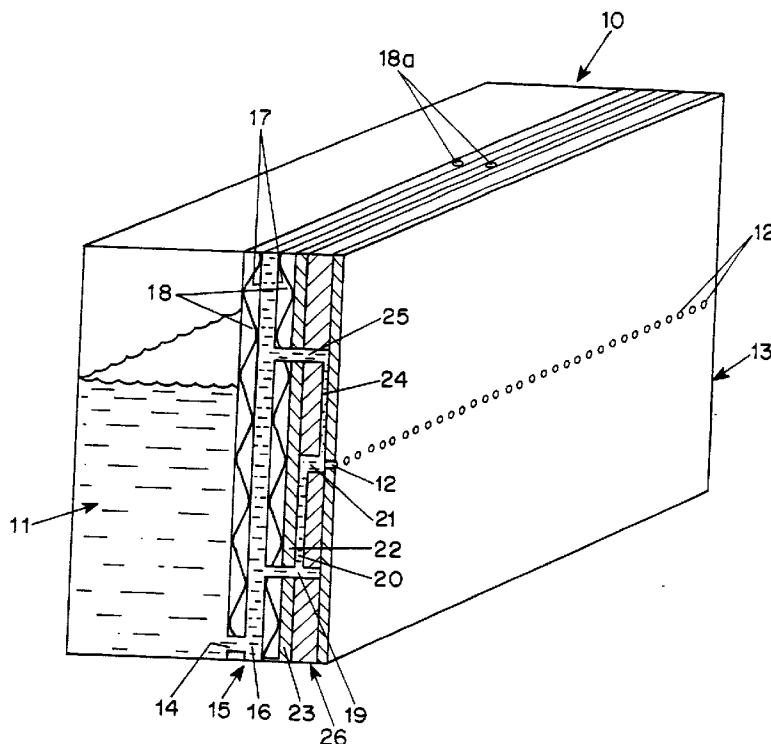
(60) Division of application No. 08/406,427, filed on Mar. 20, 1995, now Pat. No. 5,474,032, which is a continuation-in-part of application No. 08/215,301, filed on Mar. 21, 1994, now Pat. No. 5,659,346.

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(57) **ABSTRACT**

In the embodiments of the simplified ink jet head described in the specification, a carbon body is formed with ink passages, such as internal passages extending through a carbon plate, pressure chambers on one side of a carbon plate, flowthrough passages on the other side of the same plate and ink supply passages, and a piezoelectric plate is affixed to the pressure chamber side of the carbon plate by a thin layer of epoxy adhesive. The piezoelectric plate may have a conductive coating on one side which is photoetched to produce an electrode pattern corresponding to the pattern of the pressure chambers in the carbon plate. An orifice plate may have specially profiled orifice openings to assure axial projection of drops and may be affixed by a thin layer of epoxy adhesive to a carbon plate having orifice passages supplying ink from the pressure chambers to the orifices. Since the carbon plate is conductive, it can be used, if desired, as an electrode on the opposite side of the piezoelectric plate and, to assure grounding of the piezoelectric plate, a conductive epoxy adhesive may be used to bond the piezoelectric plate to the carbon plate. Moreover, since the carbon plate is porous, it can provide a communication path between a vacuum source and an air-permeable, ink-impermeable layer on the ink passages to remove dissolved air from the ink in the passages. In one alternative embodiment, an ink jet head assembly contains two separate carbon pressure chamber plates, a carbon manifold plate and a carbon collar to retain the carbon plates in an assembly.



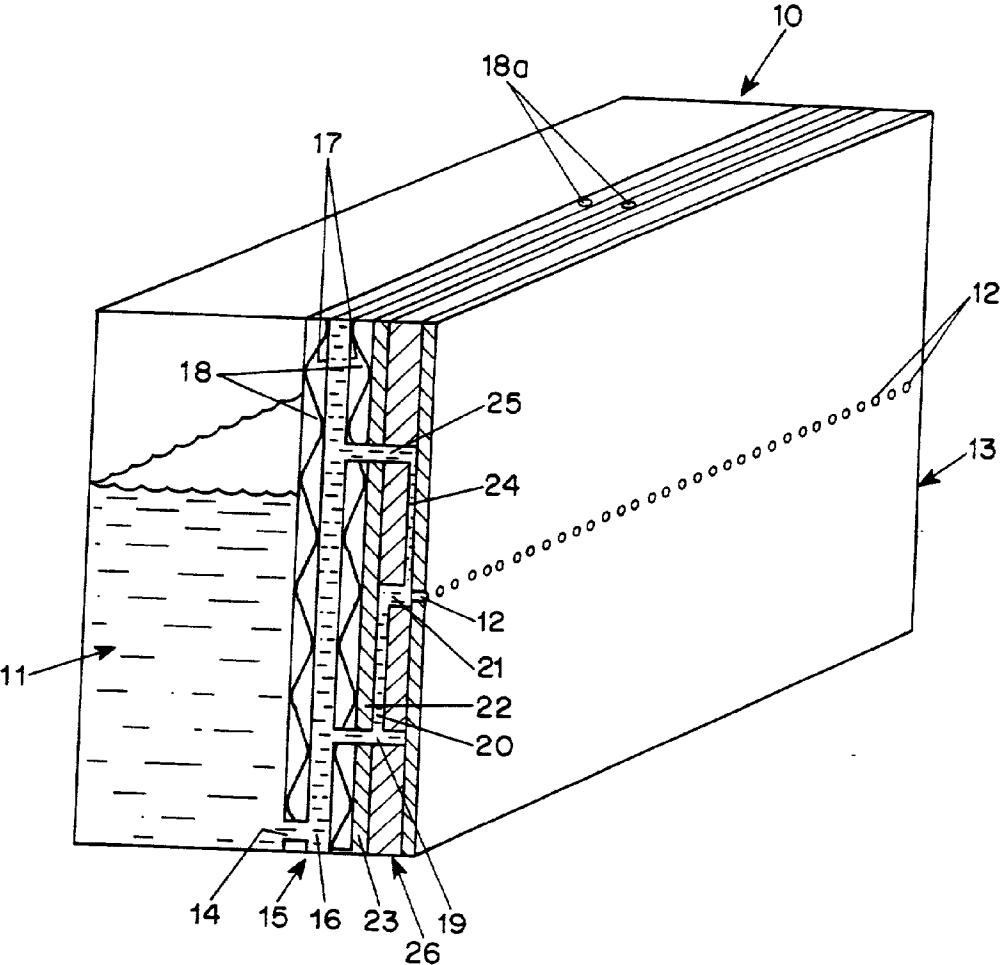


FIG. 1

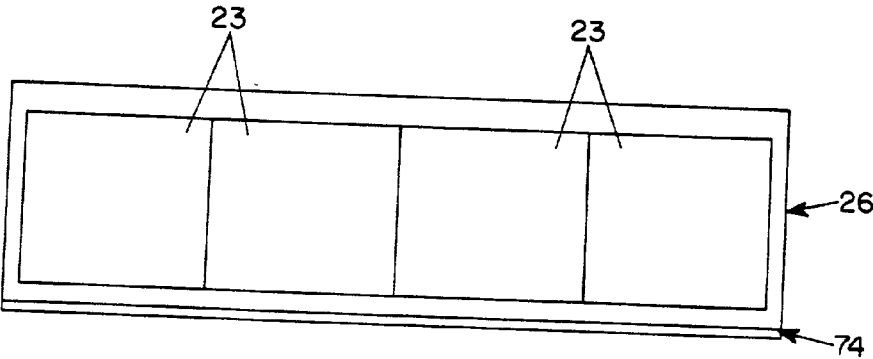


FIG. 5

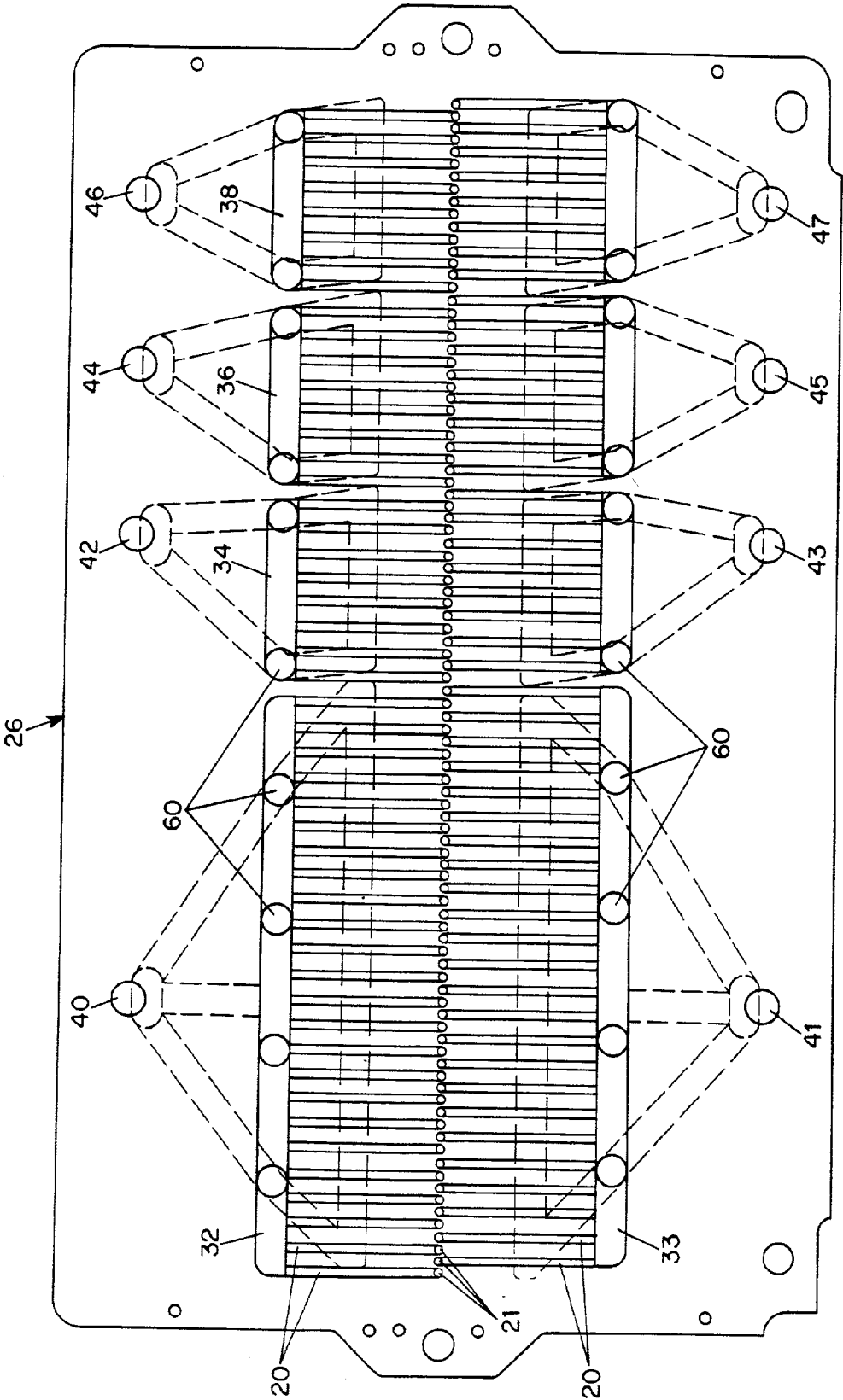


FIG. 2

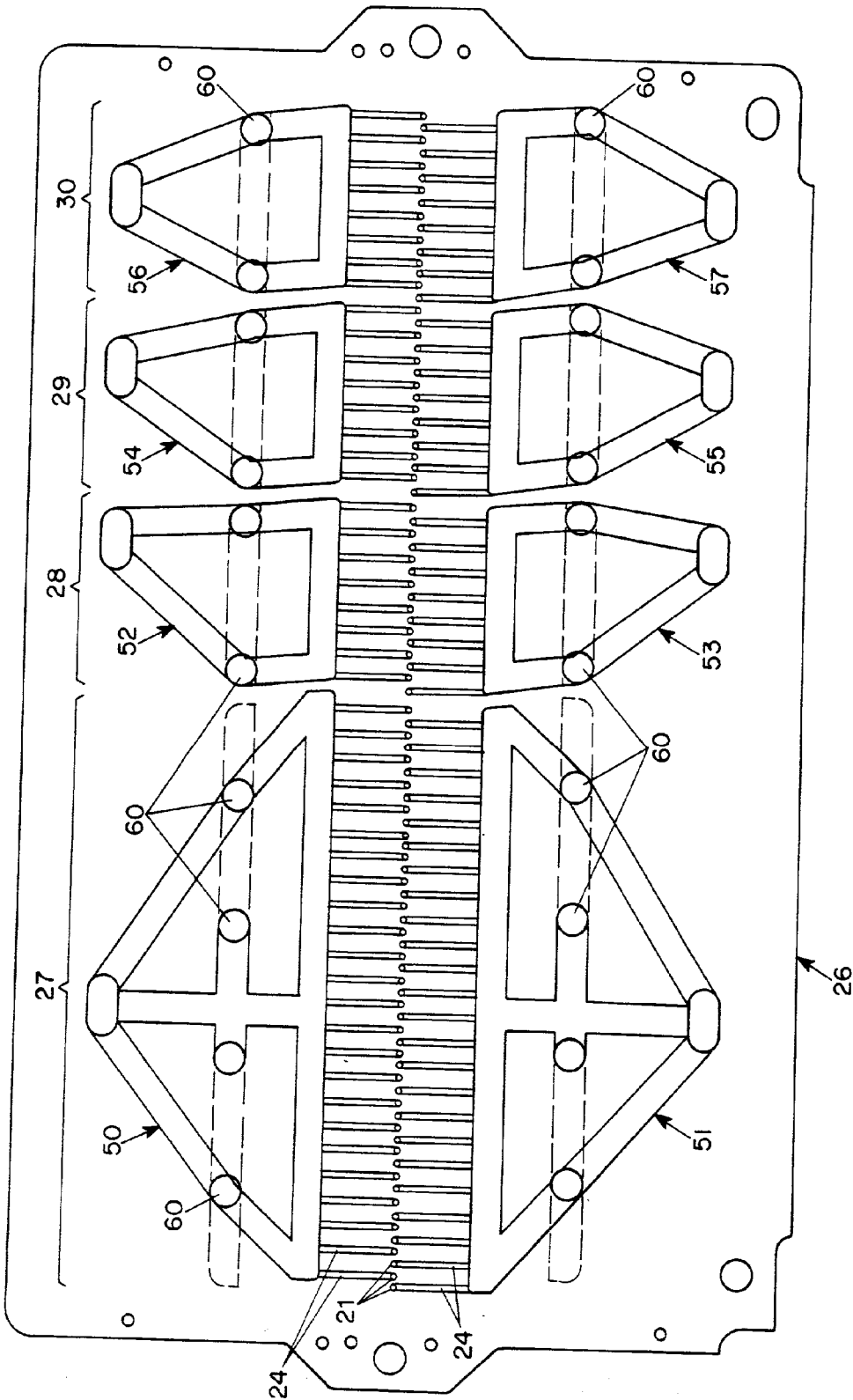
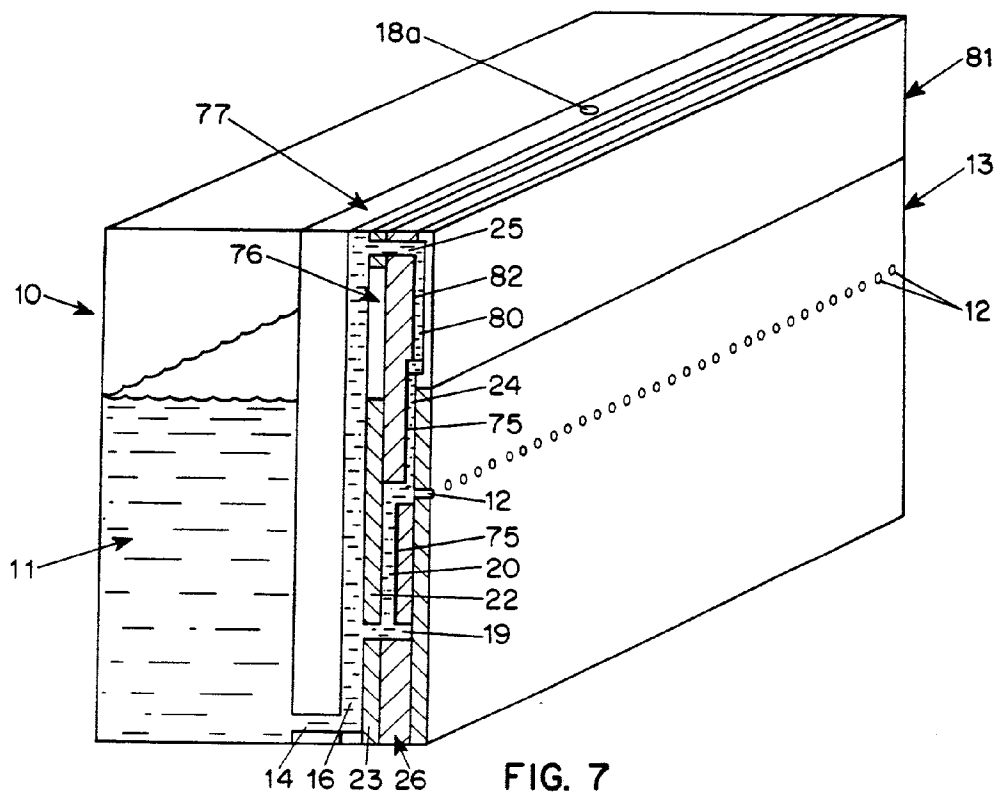
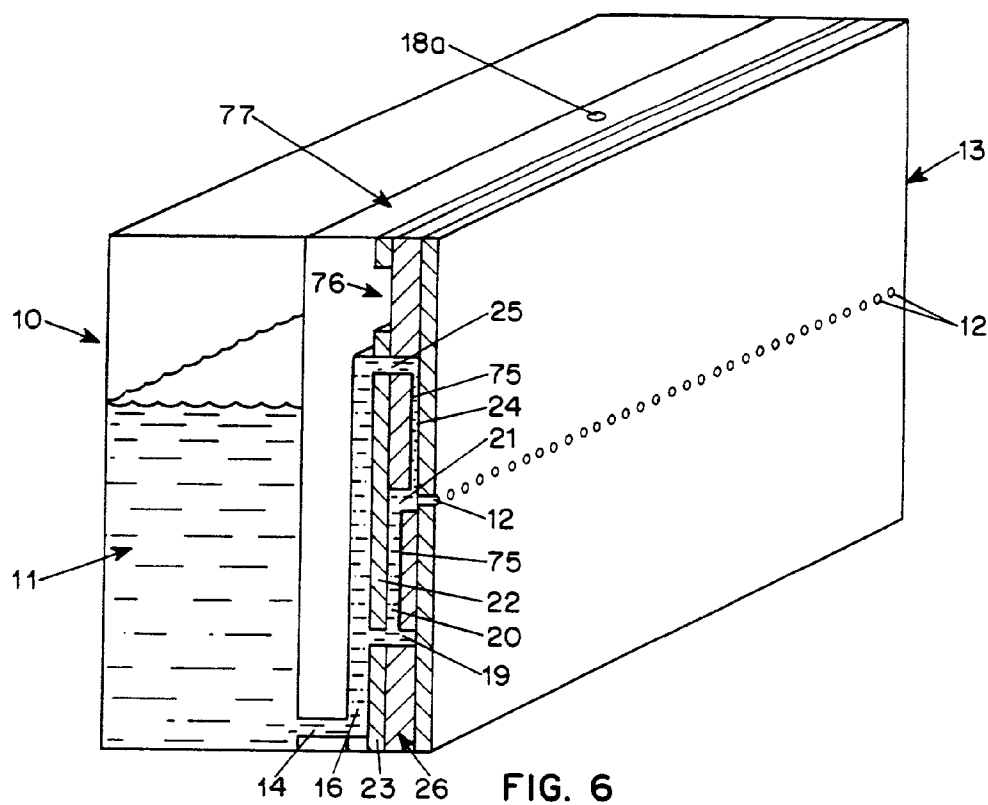


FIG. 3



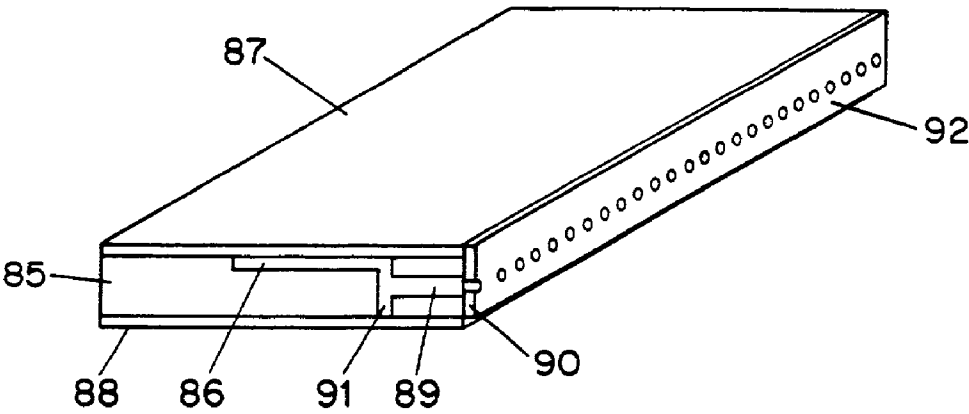


FIG. 8

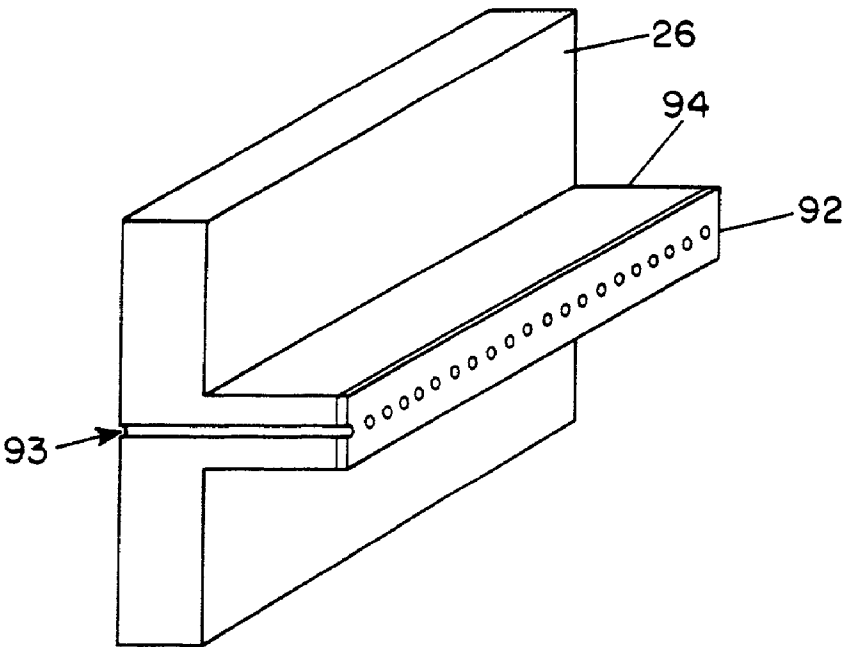


FIG. 9

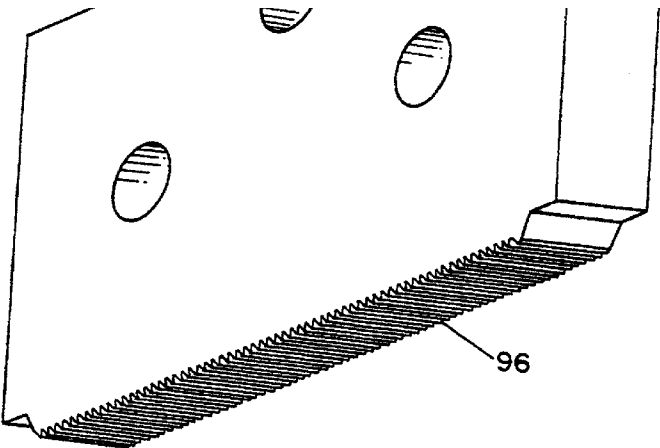


FIG. 10

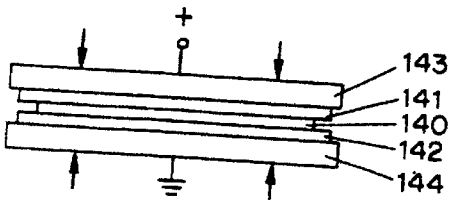


FIG. 11

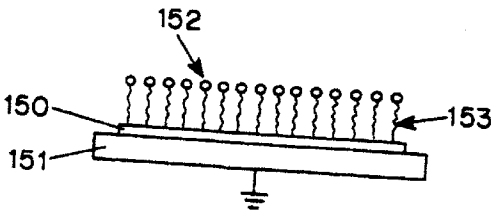


FIG. 12

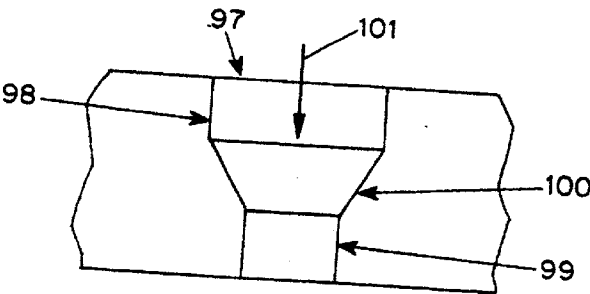
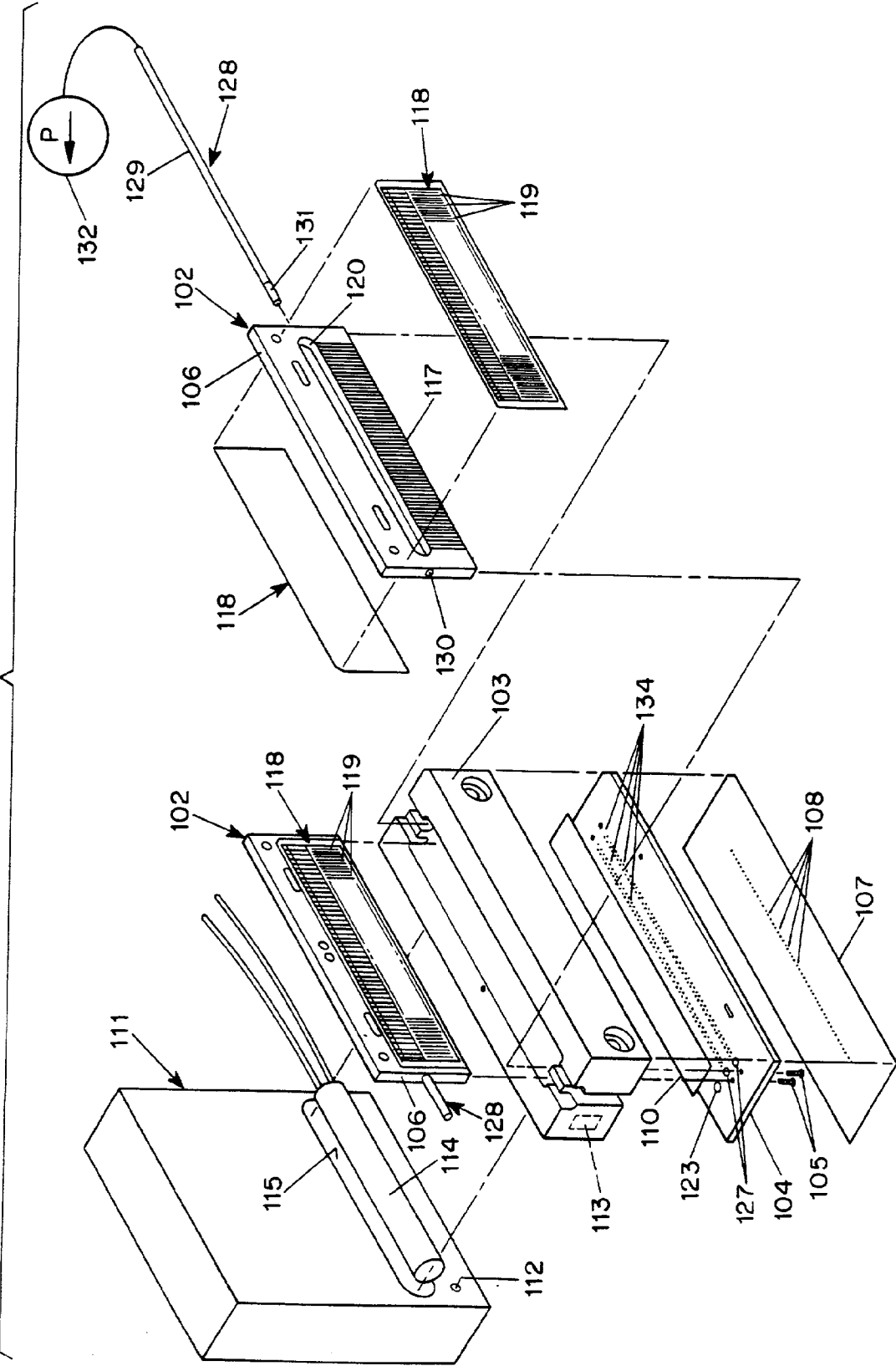


FIG. 13

FIG. 14



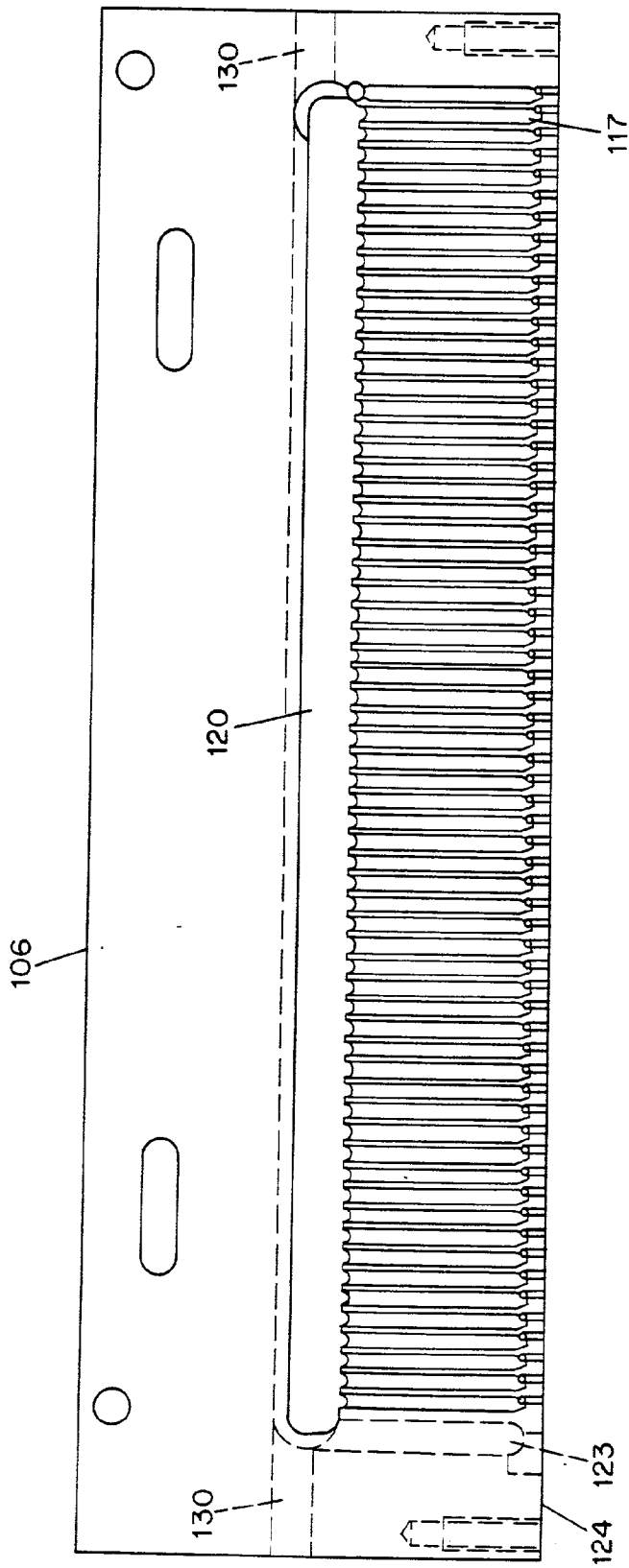


FIG. 15

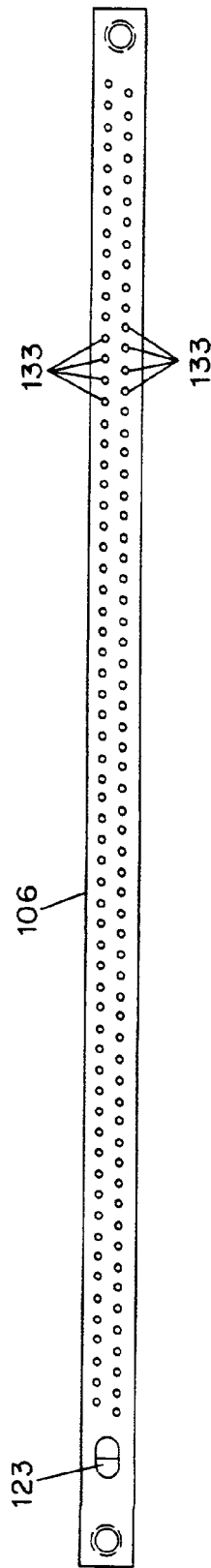


FIG. 16

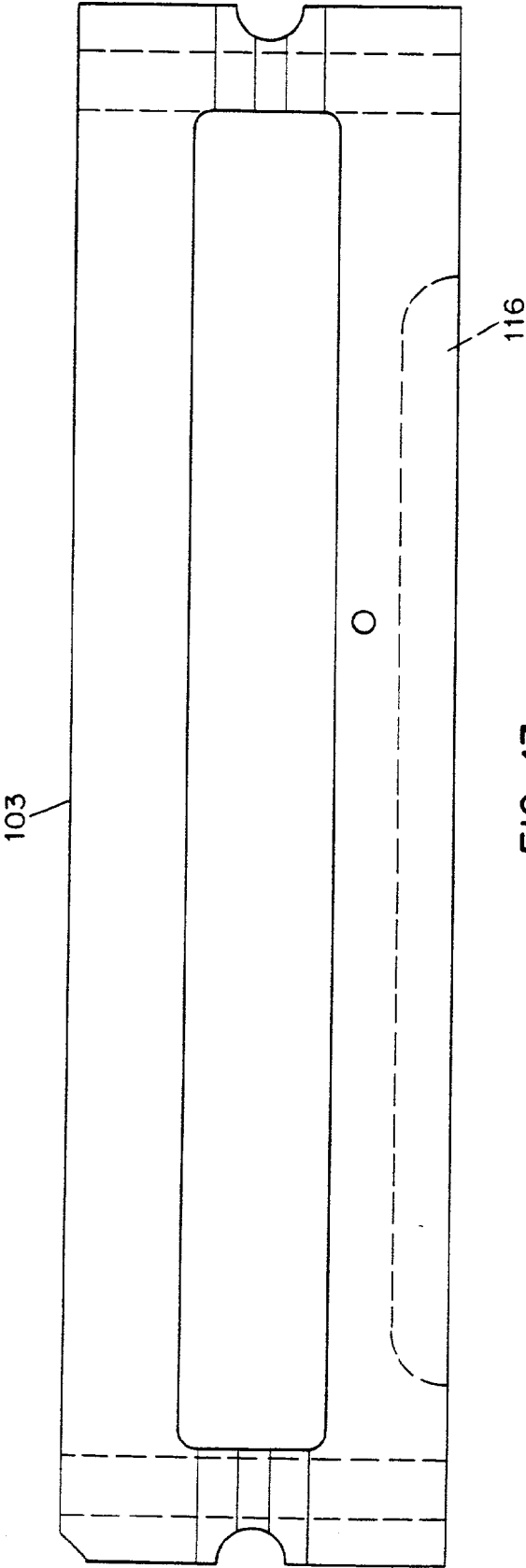


FIG. 17

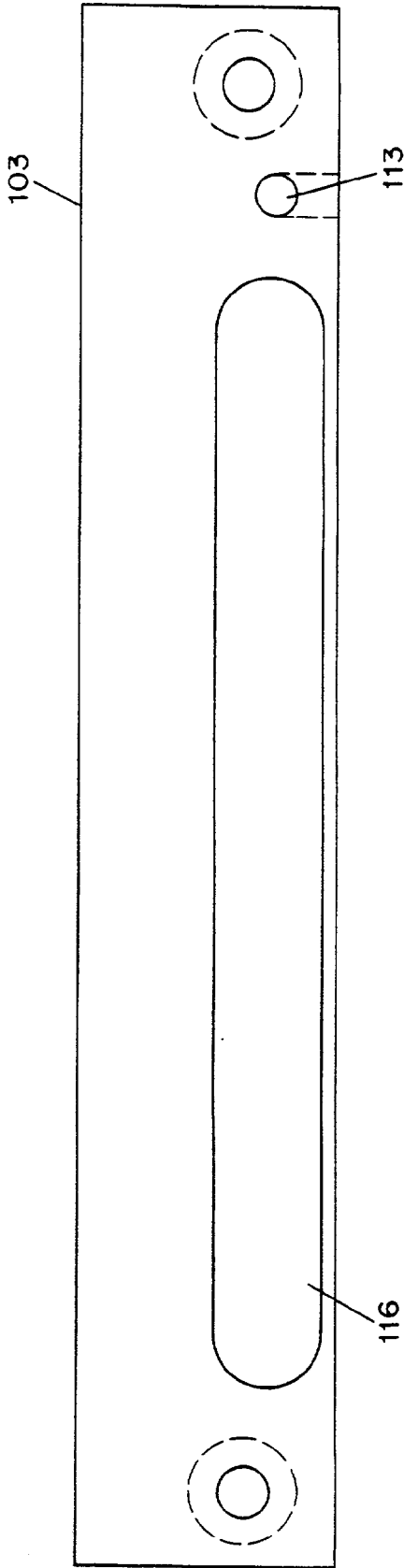


FIG. 18

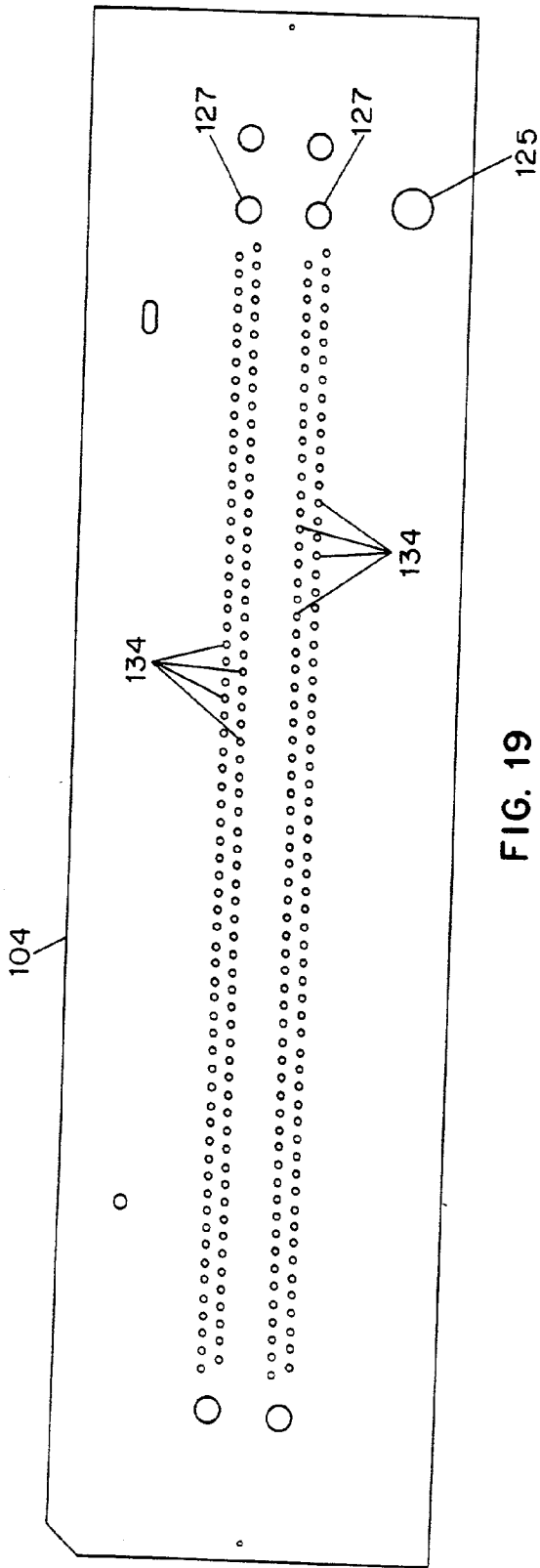


FIG. 19

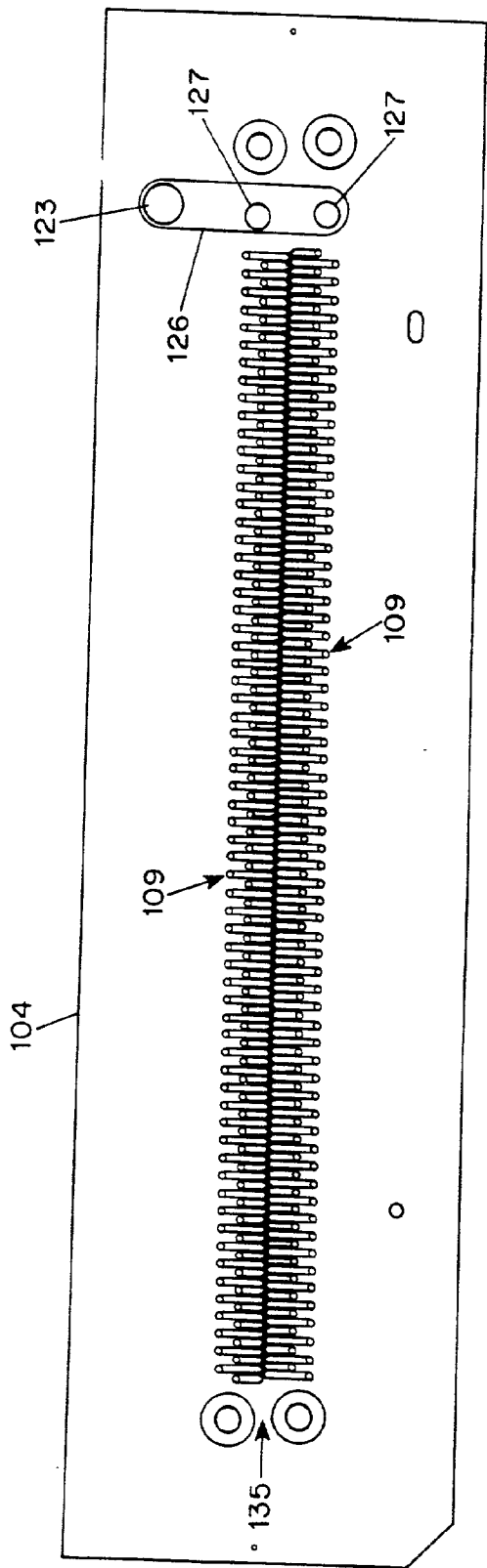


FIG. 20

SIMPLIFIED INK JET HEAD

BACKGROUND OF THE INVENTION

[0001] This invention relates to ink jet head arrangements and, more particularly, to a new and improved ink jet head arrangement having a simple and inexpensive structure.

[0002] Conventional ink jet heads, in which ink received from an ink reservoir is ejected selectively through a series of orifices, have been made using thin plates of metal or ceramic material having appropriate passages which are bonded together in adjacent relation in an assembly, as described, for example, in the Roy et al. U.S. Pat. No. 5,087,930 and the Hoisington et al. U.S. Pat. No. 4,835,554. In such arrangements, each chamber or passage in the flowpath leading from the ink inlet to the orifice, through which the ink is ultimately ejected, is provided in one or more of the several plates in the assembly. This requires an array of plates having different thicknesses, each of which must be separately machined to precise dimensions to produce the appropriate chambers and passages, and also requires precise positioning of all of the chambers and passages in the plates. Moreover, the plates must be assembled and bonded together and to a piezoelectric plate in highly precise alignment, and each plate must be flat and free from burrs that would cause voids between adjacent plates. Furthermore, because of differences in the coefficients of thermal expansion between the materials used in the plates, bond stresses are generated by temperature variations which occur in connection with the manufacture and use of the ink jet head which must be overcome.

[0003] In hot melt ink jet printheads, which operate at elevated temperatures, the printhead materials must be good conductors of heat so that the printhead will warm up quickly and the temperature gradients during operation will be small. The stresses created when parts of different materials expand differently with changes in temperature is another concern. The prime mover in a printhead is usually a piezoelectric ceramic (PZT) which has a relatively low thermal expansion coefficient. For optimum printhead design, the challenge is to find other materials which are close to this expansion. If the printhead materials cannot be matched, it is desirable to have low-modulus materials to reduce the stresses.

[0004] The ink passages in an ink jet printhead are fine features with tight tolerances. To maintain such tight tolerances, the manufacture of the printhead requires low machining forces, small tool deflection and small machining errors, no plastic deformation and no burrs. Moreover, it may be desirable, particularly in development, that the manufacture should be carried out using standard machining methods, such as grinding, milling, drilling and shaping.

[0005] In addition, the printhead should be made of materials which are chemically inert and do not change shape over time when loaded or oxidize or interact with organic chemicals found in hotmelt and other inks or with pigments or dyes in the inks.

[0006] Heretofore, some plates used in ink jet heads have been photoetched to provide the appropriate chambers and passages, which has the advantage that the plates are generally burr-free and can be made from Kovar, stainless steel and other materials that have appropriate mechanical and

thermal expansion characteristics. The materials useful for photoetching, however, have drawbacks when used in connection with ink jet heads from which hot melt ink is ejected since they generally have low thermal conductivity. In addition, the photoetching process has the disadvantage of being a batch process with lot-to-lot variations and, moreover, when used in this manner, produces a relatively large quantity of chemical waste.

[0007] Furthermore, conventional piezoelectric plates used in ink jet heads are thin, fragile and susceptible to damage during processing. Because of the greater likelihood of damage to larger plates, the maximum size of piezoelectric plates is normally quite small, for example, less than about 100 mm, which correspondingly limits the length of an array of orifices through which ink is ejected as a result of the actuation of the piezoelectric plate.

SUMMARY OF THE INVENTION

[0008] Accordingly, it is an object of the present invention to provide an ink jet head which overcomes the disadvantages of the prior art.

[0009] Another object of the invention is to provide an ink jet head having a simple structure which is inexpensive to develop, is convenient to manufacture and is capable of providing high resolution ink jet printing.

[0010] These and other objects and advantages of the invention are attained by providing an ink jet head having at least one or more components formed from a carbon member. A preferred carbon component is one in which ink pressure chambers and connecting passages from ink supply lines and to ink jet orifices are formed. In one embodiment, a carbon component is a plate having pressure chambers formed on one side and flowthrough passages to permit continuous ink circulation through the pressure chambers formed on the other side of the plate with connecting passages leading to an orifice plate and to an ink supply extending through the carbon plate. In addition, an orifice plate is affixed to one side of the carbon plate with the orifices aligned with orifice passages in the carbon plate and a piezoelectric plate is affixed to the other side of the carbon plate with actuating electrodes aligned with the pressure chambers to cause the piezoelectric material to be deflected so as to apply pressure to the corresponding pressure chamber and eject a drop of ink through a corresponding orifice in the orifice plate.

[0011] In another embodiment, a carbon pressure chamber plate is formed on opposite sides with linear arrays of pressure chambers having ink inlet and outlet passages at opposite ends. Both sides of the carbon plate are covered by corresponding piezoelectric actuation plates and a plurality of such carbon pressure chamber plates are retained in laterally adjacent relation in a carbon collar member with the ink outlet passages therein positioned in alignment with corresponding ink passages extending through a carbon manifold plate. A manifold plate has one side retained against the ends of the plurality of pressure chamber plates and has lateral ink passages formed in the opposite side leading to a line of orifices in an orifice plate mounted on the opposite side.

[0012] In accordance with one aspect of the invention, the carbon pressure chamber plate has an ink deaeration passage

through which ink is supplied to the inlet passages leading to the pressure chambers and an internally supported, thin-walled tubular member made of air-permeable, ink-impermeable material connected at one end to a source of reduced pressure is inserted into the ink deaeration passage to provide a unitary ink deaerating and pressure chamber carbon plate. This arrangement accomplishes the necessary deaeration of ink immediately before it is supplied to the pressure chambers with minimal space requirements and without necessitating recirculation of ink to an ink reservoir.

[0013] In connection with the assembly of carbon plate components of the above type in an ink jet head, it has been learned surprisingly that it is not necessary to cement or otherwise physically bond together carbon plate components having communicating passages or to provide a gasket between them. Because the engaging surfaces of such carbon plate components can be made very smooth and flat and carbon plates are sufficiently rigid to avoid flexing, such plates can be mechanically fastened together by screws or the like without causing ink to flow between the components and, if desired, a filter layer may be interposed between the surfaces of such fastened components.

[0014] Because the carbon body can be machined precisely without causing burrs using conventional machining techniques and, since carbon has a low thermal coefficient of expansion, dimensional variations resulting from thermal expansion during machining are minimized on the plate. In addition, the carbon expansion coefficient is especially compatible with the piezoelectric plate which is affixed to it, thereby reducing or eliminating stresses between the plates which might otherwise be produced by temperature variations such as occur when the ink jet head is used with hot melt ink. Moreover, carbon is chemically inert with respect to materials in which it comes in contact in an ink jet head. It does not oxidize nor does it interact with organic chemicals found in hot-melt and other inks or with pigments or dyes used in inks.

[0015] According to another aspect of the invention, the piezoelectric plate has actuating electrodes on only one side of the plate and is prepared by a photoetching technique in which a piezoelectric plate coated on one side with electrode material is affixed to the pressure chamber side of the carbon plate with the electrode material-coated side exposed. The exposed side of the plate is coated with a photoresist material and is then exposed to a desired electrode pattern in precise alignment with the pressure chamber pattern in the carbon plate, after which the photoresist is developed, the exposed electrode material is etched away, and the remaining photoresist is removed to produce an electrode pattern conforming exactly in shape and position to the pattern of pressure chambers in the carbon plate. In addition, the electrode pattern thus formed on the piezoelectric plate can include other electrical elements such as a heater to heat ink in the passages in the carbon plate.

[0016] In accordance with a further aspect of the invention, the carbon plate is porous, preferably being about 80-90% dense, and the porosity and a vacuum source communicating with the surface of the plate can extract dissolved air from ink in the ink passages separated from the porous carbon material by an air-permeable, ink-impermeable layer.

[0017] If desired, a page-size carbon plate can be prepared with a row of separate piezoelectric plates affixed to one side

of the plate. Moreover, the carbon plate may have orifice passages formed in an edge of the plate rather than in one of the sides of the plate.

[0018] Since engineering grade carbon is friable, i.e., microscopic grains are readily broken away from a carbon body, it is easily shaped without producing burrs. As described in "Graphite Machinery Made Easy", *EDM Today*, September/October 1993 pp. 24ff, the relative softness and lack of ductility of such carbon allows it to be cut at high feed rates with little distortion and low tool wear. These characteristics permit carbon blocks to be readily formed into components of ink jet heads by conventional or unique machining techniques.

[0019] In one example, the formation of an array of closely adjacent pressure chambers for an ink jet head which have a long aspect ratio and require highly precise and uniform channel dimensions, would require prohibitively long machine cycle times using a conventional end mill. In accordance with another aspect of the invention, however, the process for manufacturing a carbon plate component of an ink jet head is greatly simplified by shaping the carbon plate using a series of linear motions against the surface of the carbon plate with a shaping tool having the desired profile. For the pressure chambers of a carbon pressure plate, for example, a tool having a series of closely spaced short teeth is scraped across the surface in several strokes to produce a series of precise channels of the required dimensions. To make a row of small diameter holes of substantial depth in one end of a body, two carbon plates may be shaped in a similar way with matching arrays of grooves having a depth equal to half the diameter of the desired holes and then cemented together with the grooves in alignment. Using certain tool shapes the holes may have a hexagonal shape rather than a circular shape.

[0020] Other machining techniques especially useful in shaping carbon bodies are electric discharge machining, which facilitates convenient formation of complex shapes, and laser machining, which can be used effectively for through holes and slots.

[0021] According to still another aspect of the invention, improved directionality of ink drop ejection from orifices supplied from non-axial orifice passages is achieved by providing orifice plate orifices having cylindrical outlet nozzle passages, larger diameter cylindrical inlet passages, and a conical intermediate section joining the outlet and inlet passages.

BRIEF DESCRIPTION OF THE DRAWINGS

[0022] Further objects and advantages of the invention will be apparent from a reading of the following description in conjunction with the accompanying drawings, in which:

[0023] **FIG. 1** is a schematic perspective sectional view illustrating a representative embodiment of a simplified ink jet head arranged in accordance with the invention;

[0024] **FIG. 2** is a plan view showing the pressure chamber side of a typical carbon plate for a multicolor ink jet head showing the arrangement of the pressure chambers and the related ink passages formed in the carbon plate;

[0025] **FIG. 3** is a view of the carbon plate of **FIG. 2** from the same side shown in **FIG. 2**, but illustrating the passages formed in the opposite side of the carbon plate;

[0026] FIG. 4 is a schematic view illustrating a typical arrangement of electrodes on the exposed surface of a piezoelectric plate used with the carbon plate shown in FIGS. 2 and 3;

[0027] FIG. 5 is a schematic plan view of a typical large-size carbon plate having a series of piezoelectric plates mounted on one surface in accordance with another embodiment of the invention;

[0028] FIG. 6 is a schematic perspective view illustrating another representative embodiment of the invention;

[0029] FIG. 7 is a schematic perspective sectional view similar to FIG. 6, illustrating another typical embodiment of the invention;

[0030] FIG. 8 is a schematic perspective view illustrating a further representative embodiment of the invention;

[0031] FIG. 9 is a fragmentary perspective view illustrating a modified form of the invention;

[0032] FIG. 10 is a perspective view showing a typical shaping tool for shaping arrays of ink passages in a carbon body for use in an ink jet head;

[0033] FIG. 11 is a fragmentary view in longitudinal section showing the shape of an orifice in an orifice plate in accordance with the invention;

[0034] FIG. 12 is a schematic view illustrating one representative method for poling a piezoelectric plate;

[0035] FIG. 13 is a schematic view illustrating another representative method for poling a piezoelectric plate;

[0036] FIG. 14 is an exploded perspective view illustrating another representative embodiment of a simplified ink jet head arrangement in accordance with the invention;

[0037] FIG. 15 is a side view illustrating a representative carbon pressure chamber plate of the type used in the arrangement shown in FIG. 14;

[0038] FIG. 16 is an end view of the representative carbon pressure chamber plate shown in FIG. 15;

[0039] FIG. 17 is a top view of the carbon collar block used in the arrangement shown in FIG. 14;

[0040] FIG. 18 is a side view of the collar block shown in FIG. 17;

[0041] FIG. 19 is a plan view showing one side of a representative carbon manifold plate of the type used in the arrangement shown in FIG. 14; and

[0042] FIG. 20 is a plan view showing the opposite side of the manifold plate of FIG. 19;

DESCRIPTION OF PREFERRED EMBODIMENTS

[0043] In the typical embodiment of the invention schematically shown in FIG. 1, an ink jet head 10 includes a reservoir 11 on one side containing ink which is to be selectively ejected in the form of drops through an array of orifices 12 formed in an orifice plate 13 mounted on the opposite side of the head. Ink from the reservoir 11 is supplied through a passage 14 to a deaerator 15 in which an ink path 16 extends between air-permeable, ink-impermeable membranes 17, each of which is backed by a vacuum

plenum 18 connected through ports a to a remote vacuum source (not shown) to extract dissolved air from the ink. Deaerated ink from the passage 16 is conveyed through a passage 19 to a pressure chamber 20 from which it is ejected on demand through an orifice passageway 21 and a corresponding orifice 12 in the orifice plate 13 in response to selective actuation of the adjacent portion 22 of a piezoelectric plate 23.

[0044] The general arrangement of the ink jet head 10 and the deaerator 15 is of the type described, for example, in the Hine et al. U.S. Pat. No. 4,937,598, the disclosure of which is incorporated herein by reference. The ink in the reservoir 11 may, if desired, be hot melt ink which is solid at room temperature and liquid at elevated temperatures, in which case heaters (not shown) are mounted at appropriate locations in the ink jet head 10.

[0045] In order to permit the ink supplied to the orifices to be deaerated continuously even though ink is not being ejected through the orifices 12, the head includes a flowthrough passage 24 extending from each orifice passage 21 to a return passage 25 leading back to the deaeration path 16 in the deaerator 15, and a continuous slow circulation of ink through the duct 19, the chamber 20, the orifice passage 21, the flowthrough passage 24 and the duct 25 back to the deaerator passage 16 is maintained by thermal convection, as described, for example, in the Hine et al. U.S. Pat. No. 4,940,995 issued Jul. 10, 1990, the disclosure of which is incorporated herein by reference. For this purpose, a heater (not shown in FIG. 1) is arranged to heat the ink near the lower end of the flowpaths consisting of the passages 19, 20, 21, 24 and 25 above its normal temperature to cause a convective flow of the ink through those passages, thereby conveying the ink back to the deaerator 16.

[0046] In accordance with the invention, the passages 19, 20, 21, 24 and 25 are formed in a plate 26 made of engineering carbon graphite, which is preferably about 8090% dense, providing a slightly porous plate structure. The carbon plate 26 is machined by micromachining techniques from opposite sides to produce the chambers and passages required for the ink jet head. The carbon plate can be machined by milling, drilling, broaching, grinding and the like, using conventional tools providing high material removal rates with minimum tool wear, to produce openings with much closer tolerances than the conventional metal plates of the type described, for example, in the Hoisington et al. U.S. Pat. No. 4,835,554. Because the carbon material is friable, no burrs are produced during machining. Moreover, the coefficient of thermal expansion of the carbon graphite body is substantially the same as that of the ceramic piezoelectric material of which the piezoelectric plate 23 is made so as to reduce or substantially eliminate thermal stresses which occur between those components of the head as a result of variations in temperature.

[0047] The preferred carbon material for use in forming components on ink jet heads is polycrystalline graphite, which is a mixture of small crystals of graphite sintered with amorphous carbon (lamp black). This produces an amorphous matrix of small (0.0255 μ) grains and smaller (0.0050.2 μ) pores. This material, which is different from powdered graphite and carbon fiber materials, offers many benefits, including good thermal conductivity, coefficient of

thermal expansion close to ceramic piezoelectric materials, good machinability, dimensional stability and chemical inertness.

[0048] The thermal properties of polycrystalline graphite (Grade DFPL available from POCO Graphite, Inc., Decatur, Tex.) and other materials which might be considered for printheads are compared with those of lead zinc titanate (PZT) ceramic piezoelectric material in Table 1 below:

TABLE 1			
Material	Conductivity (W/CmK)	Thermal Expansion (μ m/deg C.)	Modulus ($\times 10^5$ kg/cm $_$)
PZT	.015	2 to 4	7
Thermoplastic (Ultem)	0.0022	56	0.15
Aluminum (6000)	1.7	23.4	7
Carbon (DFP-1)	.75	8.4	1.1

[0049] The Ultem (as well as other thermoplastics) has both poor conductivity and a very high thermal expansion coefficient. The conductivity of aluminum is attractive, but its high thermal expansion and modulus are problems. Polycrystalline carbon offers a good combination of all three properties.

[0050] A potentially prohibitive aspect of the use of carbon members for ink jet components is the forming of closely spaced arrays of pressure chambers and other multitudinous, long aspect ratio, channels with precise dimensions. Using an end mill for these features could be expected to result in excessively long machine cycle times. To overcome this problem, a desired array of adjacent channel profiles is shaped in the surface of a carbon body by a specially formed tool 95, shown in FIG. 10, in a series of repeated linear motions or "scrapes." In the tool 95 for example, an array of 64 short uniformly spaced teeth 96 may be provided at one end of the tool to cut 64 parallel pressure chambers in the surface of a carbon plate. If the tool cuts at 0.025 mm per scrape, a depth of 0.15 mm can be achieved in 6 scrapes, which requires only a few seconds of machine time. The tool 95 makes an array of channels equal to the width of the tool, and can make a wider array by taking repeat adjacent passes. Tool irregularities are averaged out by taking finish cuts in the reverse direction or at a one-tooth offset. Reversing the tool also allows the formation of steeper channel ends when this is required. This technique can be used to make pumping chambers, manifold passages, flowthrough passages, and the like. Finally, channels of variable or tapered depth can be made as well, by raising or lowering the tool as a cut is being made.

[0051] For an array of closely spaced deep, small diameter holes in a carbon body, where the depth is more than 3 times the drill diameter, drilling can become difficult and expensive. To provide an array of closely spaced holes having a diameter of, for example, 0.28 mm through a carbon plate 1.75 mm thick would require a great deal of time and a number of expensive drills. To form such an array in a simple manner, matching arrays of channels (which may be semi-hexagonal in shape) 0.14 mm deep are formed in two matching blocks of carbon which are then bonded together with adhesive to form a single block containing an array of parallel, long 0.28 mm diameter holes. This block is then

sliced perpendicularly to the axes of the holes and ground flat to form the array bodies. The adhesive joint down the middle of the array body has been found to be very strong.

[0052] Polycrystalline carbon is easily bonded by a variety of adhesives. Three systems are particularly compatible with carbon in hot melt ink jet head applications. The first is a simple dispensed epoxy which works well for coarse scale joints. The second is a thermoplastic sheet adhesive. Using this technique, a thin teflon (TFE) sheet compressed at elevated temperature and pressure provides a tenacious bond between flat surfaces of polycrystalline carbon. Similarly, acrylic sheet adhesives should perform well at lower temperature. In the third technique, a dilute sprayed B-stage epoxy system is applied to the surfaces to be bonded. This has been shown to be adaptable to the complex geometries of ink jet printheads, yet high in strength at elevated temperatures.

[0053] There is some challenge in bonding a porous material like carbon with a spray application technique. Since excess adhesive will clog small passages, and thin layers may be drawn by capillary forces into the carbon body pores, careful control of process variables is required. In particular, the carbon pore structure must be uniform, the spray-deposited layer thickness must be small compared to the particle/pore size, and the heat cure process must be tuned to the adhesive rheology.

[0054] FIG. 2 illustrates a representative arrangement of pressure chambers 20 and orifice passages 21 as viewed from the piezoelectric plate side of the typical carbon monolithic plate 26 of FIG. 1, while FIG. 3 illustrates the other ends of the orifice passages 21 and the flowthrough passages 24 which are formed in the opposite side of the monolithic array 26. FIG. 3, while showing the passages on the side of the monolithic array 26 which face the orifice plate 13, is illustrated with the passages seen as they would be viewed in the same direction as FIG. 2.

[0055] FIGS. 2 and 3 show supply passages for supplying four different color inks, e.g., black, yellow, magenta and cyan, to four different groups 27, 28, 29 and 30 of the orifice passages 21. Since black ink is normally used to a much greater extent than the colored inks, half of the orifice passages 21 are arranged to supply black ink, and one-third of each of the remaining passages are arranged to supply each of the colored inks.

[0056] As illustrated in FIG. 2, the pressure chambers 20 of the array are alternately disposed on opposite sides of the line of orifice passages 21 and are supplied from grooves formed in the pressure chamber side of the graphite plate 26, for example, from grooves 32 and 33 supplying black ink, grooves 34 and 35 supplying magenta ink, grooves 36 and 37 supplying yellow ink, and grooves 38 and 39 supplying cyan ink. The appropriate color ink is supplied to these grooves through corresponding apertures 40 and 41, 42 and 43, 44 and 45 and 46 and 47, which extend through the carbon plate 26 to corresponding sets of grooves 50 and 51, 52 and 53, 54 and 55 and 56 and 57, formed in the opposite side of the plate. Those grooves, shown in solid lines in FIG. 3 and in dotted lines in FIG. 2, communicate with further apertures 60 corresponding to the passages 19 and 25 of FIG. 1, which extend through the plate to convey ink from the deaerator ink path 16 of FIG. 1 to the pressure chamber supply grooves 3239. As shown in FIG. 3, the flowthrough

passages **24** convey ink between the orifice passages **21** and the groove patterns **5057** on the opposite side of the carbon plate to complete the continuous path for circulation of ink through the deaerator **15**.

[0057] In addition, the carbon plate **26** is especially advantageous for ink jet heads used with hot melt ink. Because of its high thermal conductivity, the carbon plate provides excellent heat conduction from heaters mounted at relatively remote locations in the head to all of the ink passages in the head. This assures that the hot melt ink at each of the orifices **12** is at the same temperature and therefore has the same viscosity, thereby providing good uniformity of operation throughout the length of the array of orifices.

[0058] A typical carbon plate **26** may be about 2 mm thick and have orifice passages **21** about 0.2 mm in diameter, pressure chambers about 9 mm long, 0.5 mm wide and 0.2 mm deep, supply grooves about 1.0 to 1.5 mm wide and 0.5 mm deep, flowthrough passages about 4 mm long, 0.1 mm wide and 0.05 mm deep, and apertures **60** about 1.5 mm in diameter. With this arrangement, a 96 aperture linear array of the type shown in the drawings can be provided in a carbon plate **26** having dimensions of about 4 cm by 7 cm with the orifice passages **21** spaced by about 0.5 mm. When oriented at an appropriate angle with respect to the scanning direction, an ink jet head using an array of this type can produce a resolution of about 300 dots per inch (120 dots per cm) in the subscanning direction and, when actuated at a rate of about 14 KHz at a scanning rate of 1 m/sec to produce 100 picoliter drops, can produce the same resolution in the scanning direction.

[0059] In certain high-frequency ink jet applications, the rigidity of the walls of the pressure chambers **20** formed in the carbon plate may be less than desired, requiring a higher operating voltage for the piezoelectric actuating plate. To alleviate this, the surfaces of the pressure chambers **20** formed in the carbon plate may be coated with a thin layer, such as 0.01 to 0.1 mm thick, of a very hard (i.e., high modulus of rigidity) material such as a carbide or nitride, e.g., silicon carbide or nitride, boron carbide or nitride, tungsten carbide or nitride, tantalum carbide or nitride, or the like. Preferably, the coating is applied by chemical vapor deposition.

[0060] In order to actuate the piezoelectric plate **23** so as to selectively eject ink from the pressure chambers **20** through the orifice passages **21** and through corresponding orifices **12** in the orifice plate **13**, the piezoelectric plate **23**, which is mounted on the pressure chamber side of the carbon plate, has no electrodes on the carbon plate side and is patterned with an electrode array of the type shown in FIG. 4 on the exposed side. In the array shown in FIG. 4, a common electrode **65** extends along the portion covering the orifice passage array in the carbon plate and also extends laterally into regions **66** over the carbon plate surface portions between the pressure chambers.

[0061] Interlaced between the lateral extensions **66** is a spaced array of individual electrodes **67** which are positioned directly over the pressure chambers in the carbon plate so that, when selectively actuated by application of appropriate potential to a corresponding terminal **68**, the piezoelectric plate **23** is mechanically distorted in the shear mode in the direction toward the adjacent pressure chamber **20** so as to cause ejection of an ink drop from the orifice with

which that pressure chamber communicates. Shear-mode operation of a piezoelectric plate is described, for example, in the Fischbeck et al. U.S. Pat. No. 4,584,590, the disclosure of which is incorporated herein by reference. Such shear-mode operation does not require any electrode on the opposite side of the piezoelectric plate but, if desired, the carbon plate **26**, being conductive, can be used to provide an electrode on the opposite side of the plate.

[0062] The electrode pattern shown in FIG. 4 also includes a heater conductor **70** having a thermistor temperature control switch **71** extending between two terminals **72** and **73** and arranged to heat the ink in the passages in the lower portion of the carbon plate **26** so as to cause circulation of the ink in the manner described above by thermal convection. Because the carbon material in the plate **26** has a high thermal conductivity, the plate acts as a thermal conductor between the heater and the adjacent ink passages in the plate.

[0063] In order to form an electrode pattern of the type shown in FIG. 4 on the piezoelectric plate **23**, the plate, which is initially provided with a continuous conductive coating on the exposed side, is permanently affixed by an epoxy adhesive to the pressure chamber side of the carbon plate **26**. Since the carbon plate is slightly porous, an epoxy adhesive can be used to mount not only the piezoelectric plate **23**, but also the orifice plate **13**, to the opposite surfaces of the carbon body. For this purpose, one of the surfaces of the plates to be joined is preferably spray-coated with a layer of B-stage epoxy adhesive about 2 microns thick before the piezoelectric plate **23** or the orifice plate is applied to it. Such a thin layer of epoxy adhesive provides excellent seals between the plates, including the very narrow portions between the orifice passages, but does not flow into the passages or apertures in such a way as to interfere with the operation of the head.

[0064] In order to ground the surface of a the piezoelectric plate which is bonded to the carbon body, the epoxy adhesive may be doped with conductive particles. Alternatively, the clamping force applied during bonding of the piezoelectric plate to the carbon body is increased until the epoxy adhesive is driven into the carbon body to provide a large number of point contacts between the plate and the carbon body.

[0065] The use of single sided piezoelectric plates requires special techniques for poling the plates. According to one technique, schematically shown in FIG. 11, a piezoelectric plate **140** is compressed between two electrodes **141** and **142** separated from the plate **140** by two slightly conductive rubber sheets **143** and **144** to provide intimate electrical contact throughout the surfaces of the plate while limiting the current available for arcing if a breakdown occurs. When this procedure is carried out in two steps to minimize piezo stresses, high yield poling of unmetallized piezoelectric plates is achieved.

[0066] The other poling technique, shown in FIG. 12, uses a corona discharge to set up a poling field across the piezoelectric plate. A piezoelectric plate **150** is laid on a flat ground plate **151**, and a corona discharge device **152** rains charges **153** down onto the surface. When the applied charge is sufficient to create an occasional breakdown through the plate, which is nondestructive because of the high surface resistance of the piezoelectric material, the plate is poled.

This process is preferably carried out at an elevated temperature, such as 100-150° C., to ameliorate poling stresses.

[0067] The orifices **12** in the orifice plate **13** of **FIG. 1**, which may be a stainless steel plate about 0.05 mm thick, are preferably about 0.05 mm in diameter and are formed by electrical discharge machining. By selecting the appropriate size wire and controlling the current/voltage profile, the size and shape of the orifice can be controlled accurately. Bonding of the orifice plate to the surface of the carbon body is accomplished in the same way as the bonding of the piezoelectric plate.

[0068] With conventional bell-mouthed shaped orifices in an orifice plate of the type shown, for example, in the Hoisington et al. U.S. Pat. No. 5,265,315 in which the orifice diameter decreases at a continuously decreasing rate from a large diameter on the side of the orifice plate facing the ink jet head to a smaller diameter about one-third that of the large diameter on the side of the orifice plate through which the ink drop was ejected, the direction of ink drop ejection is very sensitive to asymmetries in the ink path near the periphery of the entrance to the bell-mouthed orifice. Moreover, it is not possible to space such bell-mouthed orifices as closely as desired for high resolution printing.

[0069] To overcome this problem, electrical discharge machining is used to form orifices **97** having the shape shown in **FIG. 13** with a cylindrical inlet section **98**, a smaller diameter cylindrical nozzle section **99** providing the outlet from the orifice plate and a tapered section **100** having a conical surface joining the inlet section and the nozzle section. It has been found that with an orifice design of this type, the non-axial velocity component of an ejected drop, i.e. the extent of deviation from the axial arrow **101** resulting from asymmetry of the passage leading to the orifice is reduced by more than 50%.

[0070] In a typical orifice plate **13** having a thickness of 0.05 mm, a nozzle **99** having a diameter of 0.054 mm and a length of 0.01 mm, a tapered section **100** having a cone angle of 30° and a length of 0.01 mm and an inlet section **98** having a diameter of 0.11 mm and a length of 0.03 mm, a substantial improvement in axial projection of drops supplied from an asymmetric ink path leading to the orifice was obtained. For an orifice plate **13** having a thickness of 0.075 mm and having the same nozzle and tapered section dimensions described above, and having an inlet section 0.055 mm long, a similar improvement in the direction of projection of drops was obtained at a slightly increased pressure drop. Preferably, the diameter of the inlet portion **98** of the orifice is no more than twice the diameter of the nozzle portion **99** and the length of the inlet portion **98** is greater than that of the nozzle portion. Such orifice shapes having successive conical and tapered cylindrical sections can be obtained by appropriate conventional electrical discharge machining techniques.

[0071] In accordance with one aspect of the invention, after the piezoelectric plate **23** has been affixed to the carbon plate, a layer of photoresist material is coated on the exposed surface and, using the precisely known positions of the pressure chambers from a reference edge in the carbon body, the photoresist is exposed to produce a pattern which corresponds exactly with the locations of the pressure chambers, and the unexposed resist is removed in the usual manner. Thereafter, the conductive layer is etched away

from the exposed surface of the piezoelectric plate and the remaining resist is then removed to provide the final electrode pattern.

[0072] In this way, the piezoelectric plate **23**, which is preferably only about 0.1 to 0.25 mm thick and is quite fragile, is protected from damage during the formation of the electrode pattern and other head-manufacturing steps. Consequently, substantially large piezoelectric plates, for example, 50 mm by 100 mm or more, can be used without substantial risk of damage during processing. Moreover, large-scale production is facilitated since a large-size carbon plate can be machined with multiple identical or similar patterns, and a corresponding number of piezoelectric plates can be bonded to the pattern locations on the large sheet and simultaneously exposed and etched to form electrode patterns corresponding precisely to the structures of the adjacent portions of the carbon plate, after which the large-size plate is separated into individual plates.

[0073] Furthermore, instead of separating a large-size carbon plate into smaller plates, a single carbon plate 20 cm wide, or even 150 cm wide, if appropriate, may be made to provide a page-width ink jet head by mounting a row of piezoelectric plates to one surface and simultaneously processing the piezoelectric plates in the manner described above. A typical page-width inkjet head is shown in **FIG. 5**, in which a carbon plate **26** has a row of adjacent piezoelectric plates **23** affixed to one side. The ink jet head of **FIG. 5** has internal passages arranged to supply ink to an orifice plate **74** mounted on one edge, as described hereinafter with respect to **FIG. 8**. Alternatively, if desired, the large-size plate **26** of **FIG. 5** may have internal passages of the type described above with respect to **FIG. 1** leading to an orifice plate (not shown in **FIG. 5**) mounted on the opposite side of the carbon plate.

[0074] As an alternative to the deaerator arrangement **15** shown in **FIG. 1**, the use of a carbon plate **26** which is slightly porous permits the plate to act as a conduit between the vacuum plenum and the ink in the passages within the carbon plate in the manner shown in the alternative embodiment of **FIG. 6** so that dissolved air can be extracted. For this purpose, the surfaces of the plate passages are coated with a layer **75** of an air-permeable, ink-impermeable epoxy resin and one or more openings **76** are provided in the piezoelectric plate **23** to expose the adjacent surface of the carbon plate **26** to a vacuum source **77** which replaces the deaerator **15**, the other exposed surfaces of the carbon plate **26** being sealed to prevent entry of air into the porous plate. The vacuum source **77** may be connected to a remote vacuum supply through the port **18a**, or it may be a replaceable vacuum reservoir of the type described in the copending Hine application Ser. No. 08/143,165, filed Oct. 26, 1993, the disclosure of which is incorporated herein by reference.

[0075] In another modified deaerator arrangement shown in **FIG. 7**, ink passages **80** extending between the passages **24** and **25** are formed in a plate **81** which is mounted on the front surface of the carbon plate **26** and an air-permeable, ink-impermeable membrane **82**, similar to the membranes **17** of **FIG. 1**, is positioned between the carbon plate **26** and the plate **81**. In this case, the coating **75** applied to the various passages within the carbon plate **26** is impermeable to air and only the portion of the plate **26** adjacent to the

membrane **82** is used to extract air from the ink in the passages **80**. If desired, a filter may also be incorporated in the plate **81** in the path of the ink between the passages **24** and **25**. Otherwise, the arrangement of **FIG. 7** is the same as that shown in **FIG. 6**.

[**0076**] Because the high thermal conductivity of the carbon plate **26** assures heat conduction from relatively remote heaters through the carbon plate to hot melt ink adjacent to an orifice plate, a hot melt ink jet head according to the invention may be arranged so that the ink is ejected from an orifice plate mounted on an edge of a carbon plate rather than from an orifice plate mounted on one side of the carbon plate. Moreover, even if the ink used in the ink jet head is not hot melt ink, the easy machinability of the carbon plate provides a distinct advantage in an arrangement of this type in contrast to a conventional laminated plate arrangement, in which edges of the plates adjacent to the orifice plate cannot be perfectly aligned, leading to irregularities in the mounting of the orifice plate.

[**0077**] This arrangement is shown in **FIG. 8**, in which a carbon plate **85** has pressure chambers **86** formed in one side and a piezoelectric plate **87** affixed to that side of the plate, and a bottom cover plate **88** affixed to the opposite side of the plate. A row of orifice passages **89**, which are drilled into one edge **90** of the carbon plate **85**, communicate with the pressure chambers **86** through perpendicular passages **91** extending through the plate **85**. With a carbon plate **85** of this type, the end surface **90** can be ground perfectly flat and the plate can then be drilled to form the passages **89** and **91** to connect with the pressure chambers **88**, after which an orifice plate **92** is affixed to the edge **90** by epoxy adhesive in the manner described above.

[**0078**] An ink jet head made in this way is especially advantageous, not only because it requires only a very narrow strip for the orifice plate **92**, but also because it permits the bulk of the printhead to be spaced from the paper path and also permits stacking of multiple printheads.

[**0079**] If desired, the ink jet head of **FIG. 1** can be modified to provide similar advantages by forming the carbon plate **26** with a projecting portion **94** through which orifice passages **93** extend to an orifice plate **92**, as illustrated in **FIG. 9**.

[**0080**] In a further embodiment of the invention shown in **FIGS. 1420**, an ink jet head is assembled from a plurality of carbon components. In this embodiment, as illustrated in the exploded view of **FIG. 14**, two carbon pressure plate assemblies **102**, described in greater detail hereinafter, are assembled in a carbon collar **103** so that their end surfaces, which contain ink outlet passages, are aligned with corresponding openings in a manifold plate **104** to which the pressure chamber plate assemblies **102** are affixed by screws **105** extending through the manifold plate and into an adjacent pressure chamber plate **106**. An orifice plate **107** has a linear array of closely spaced orifices **108** which are aligned with the ends of arrays of passages **109** (**FIG. 20**) in the manifold plate **104** so as to eject ink in response to selective actuation of the pressure plate assemblies.

[**0081**] Interposed between the ends of the pressure plate assemblies **102** and the manifold plate **104** is a filter layer **110** having pores or openings slightly smaller than the orifices **108** in the orifice plate **107** so as to prevent poten-

tially orifice-clogging solid material from reaching the orifices **108** but large enough to permit particles of solid material smaller than the size of the orifices to pass through the filter layer. This type of filter is described, for example, in the copending Moynihan et al. application for "Filter Arrangement For Ink Jet Head" Ser. No. 08/231,102, filed Apr. 22, 1994.

[**0082**] An ink reservoir **111**, mounted against one side of the collar **103** has an ink supply opening **112** which supplies ink to the collar **103**. As best seen in **FIG. 16**, a corresponding opening **113** in the collar is aligned with the opening **112** to receive ink from the reservoir **111**. In addition, if hot melt ink is to be used in the ink jet head, a cartridge heater **114** is mounted in a groove **115** formed in the side of the reservoir and in a corresponding groove **116** (**FIG. 18**) in the side of the collar **103** and is controlled so as to maintain the ink within the assembled ink jet head at a desired temperature during operation of the system.

[**0083**] Each pressure chamber assembly **102** includes a pressure plate **106** having arrays **117** of closely spaced pressure chambers formed on opposite sides of the plate **106** and each of those arrays is covered by a piezoelectric plate **118** of the type described previously with respect to **FIG. 4**, having an array of electrodes **119** arranged with respect to the array of pressure chambers **117** to change the volume of the corresponding pressure chamber in response to appropriate electrical signals.

[**0084**] The pressure chamber plate **106**, which is illustrated in greater detail in **FIGS. 15 and 16**, has a longitudinally extending opening **120** which, in the illustrated embodiment receives ink through an internal passage **123** terminating at an end surface **124** which faces the manifold plate **104** as seen in **FIG. 14**. As shown in **FIG. 19**, the surface of the manifold plate **104** facing the pressure chamber plate, has an opening **125** which receives ink from the collar passage **113** and supplies it to a groove **126** (**FIG. 20**) on the opposite side of the manifold plate, from which ink passes through two further openings **127** in the manifold plate to the passages **123** in the pressure plates **106** so that the ink is distributed through the longitudinal opening **120** to all of the pressure chambers in both of the arrays **117** in each plate.

[**0085**] In order to extract dissolved air from the ink as it is being supplied to the arrays **117** of pressure chambers, a deareator **128** consisting of a tubular member **129** made of air-permeable, ink-impermeable material, such as extruded polytetrafluoroethylene having a 0.1 mm wall thickness and a 1.5 mm internal diameter, extends through an opening **130** in the edge of each pressure chamber plate **106** and into the longitudinal opening **120**. A plug **131** closes the inner end of the tube and the end projecting out of the opening **130** in the plate **106** is connected to a vacuum source **132** supplying sufficient negative pressure, such as 0.7 atmosphere, to reduce the dissolved air content of the ink being supplied to the pressure chambers below the level at which air bubbles can form in the pressure chamber during operation of the ink jet system. In order to prevent the tube **129** from collapsing in response to application of negative pressure, a porous support, such as a rod of porous carbon or a helical wire having a diameter substantially equal to the internal diameter of the tube, is inserted into the tube.

[**0086**] As shown in **FIG. 16**, the end surface **124** of the carbon plate **106** has two arrays of ink passages **133** which

extend perpendicularly to the end surface **123** and each of those passages communicates internally with the adjacent end of a corresponding pressure chamber in the arrays **117**. Consequently, upon actuation of one of the pressure chamber, ink is forced out of the plate **106** through a corresponding one of the passages **133**.

[0087] After passing through the filter layer **110**, ink from each of the passages **133** is supplied through a corresponding passage **134** in an adjacent surface of the manifold plate **104** shown in FIG. 17 and, as shown in FIG. 20, the arrays of passages **109** in the opposite surface of the manifold plate extend horizontally along the surface of that plate to convey the ink supplied through the passages **134** in a lateral direction toward the center of the manifold plate. Those passages terminate in a central line **135** extending longitudinally along the manifold plate so as to be in line with the line of ink jet orifices **108** in the orifice plate **107**.

[0088] Although carbon is the preferred material for the manifold plate **104**, especially for ink jet heads used with hot melt ink, other materials which can be formed with a sufficiently flat surface and which have a thermal expansion coefficient compatible with adjacent components may also be used. For example, steel and ceramics such as alumina and glass, in which appropriate passages can be formed by photoetching, may also be used to form the manifold plate.

[0089] In a typical embodiment of the type shown in FIGS. 1420, each pressure chamber plate **106** is approximately 75 mm long, 22 mm wide and 2.5 mm thick and each pressure chamber array **117** contains 64 pressure chamber approximately 9 mm long, 1 mm wide and 0.15 mm deep and the manifold plate **104** is approximately 1.4 mm thick.

[0090] Heretofore it was believed that the total length of the descender, which is the ink path leading from the end of the pressure chamber to the orifice in the orifice plate, should be as short as possible, i.e. no more than about 1 mm. Although it is clear that each descender should have a constant cross-section similar to that of the pumping chamber so that its acoustic properties do not result in undesirable reflections, and that it should be short enough that viscous flow losses are not excessive and that it should also be fluidically stiff so that pressure energy losses from the surrounding structure are not excessive, it has now been determined that, in ink jet heads made of carbon components, the descender need not be so limited in length and can consist of a plurality of passages such as those in the manifold plate and within the pressure chamber plate which total as much as 7 mm in length without loss of performance. This permits greater flexibility in the design of ink jet heads in several respects. For example, the piezoelectric plate, which is quite fragile, can be spaced a significantly greater distance away from the substrate being printed by the head and the body of the ink jet array may be made thick enough to be mechanically robust and to provide good thermal uniformity. Moreover, laterally spaced pressure chambers such as those in the arrays **117** may be connected through laterally spaced passages **133** to supply ink to a single line of orifices **108** by using an arrangement of laterally directed passages **109** such as that incorporated into the manifold plate **104**.

[0091] With the simplified ink jet head according to the invention, the problems caused by burrs and dimensional variations resulting from heat produced in machining, by

differences in temperature coefficient of expansion of the materials used in the ink jet head, and by the necessity for assembling a number of previously formed plates in precise relation, and the problems of bond stresses during temperature cycling are effectively eliminated in a convenient and inexpensive manner. Moreover, the number of steps required for the formation of the electrode pattern on the piezoelectric plate and application of the plate to the ink jet head is substantially reduced and variations in electrode positioning with respect to the pressure chamber positions are eliminated.

[0092] Although the invention has been described herein with reference to specific embodiments, many modifications and variations therein will readily occur to those skilled in the art. Accordingly, all such variations and modifications are included within the intended scope of the invention.

We claim:

1. An ink jet head comprising at least one member made of carbon and formed to provide at least one ink passage in the member.
2. An ink jet head according to claim 1 wherein the carbon member is formed with an array of closely spaced ink passages.
3. An ink jet head according to claim 2 wherein the array of closely spaced ink passages extend along a surface of the carbon member.
4. An ink jet head according to claim 2 wherein the array of closely spaced ink passages extend within at least a portion of the carbon member.
5. An ink jet head according to claim 5 wherein the carbon member includes two sections each formed on a surface with an array of closely spaced grooves, the two sections being bonded together with the grooves in alignment to form the array of closely spaced passages within the member.
6. An ink jet head according to claim 2 wherein the carbon member comprises a pressure chamber plate formed with an array of closely spaced pressure chamber passages along one side surface and a corresponding array of orifice passages extending through an adjacent end surface of the member and communicating with the corresponding pressure chamber passages.
7. An ink jet head according to claim 2 wherein the carbon member includes an array of closely spaced ink passages formed in a surface of the carbon member and a corresponding array of internal ink passages communicating with the surface passages.
8. An ink jet head according to claim 7 wherein the carbon member is a pressure chamber member and wherein the ink passages formed in a surface of the pressure chamber member comprise pressure chambers, and including a piezoelectric plate affixed to the surface of the pressure chamber member.
9. An ink jet head according to claim 8 wherein the piezoelectric plate is affixed to the surface of the pressure chamber member with a conductive adhesive material.
10. An ink jet head according to claim 8 wherein the piezoelectric plate is affixed to the surface of the pressure chamber member with an adhesive material and wherein the surfaces of the pressure chamber member and the piezoelectric plate are in point-to-point physical contact.
11. An ink jet head according to claim 8 wherein the array of pressure chambers is formed in a first surface of the pressure chamber member and includes a second array of

closely spaced pressure chambers formed in a second surface of the pressure chamber member which is parallel to the first surface and a second array of internal ink passages corresponding to and communicating with the second array of pressure chambers and a second piezoelectric plate affixed to the second surface of the pressure chamber member.

12. An ink jet head according to claim 11 including a second carbon pressure chamber member having first and second arrays of closely spaced pressure chambers formed in first and second parallel surfaces, respectively, and having first and second arrays of closely spaced internal ink passages and also having first and second piezoelectric plates affixed to the first and second surfaces, respectively, a carbon collar member for holding the pressure chamber member and the second pressure chamber member in fixed parallel relation with outlet openings from the arrays of internal passages therein terminating in a common plane, and a carbon manifold member having a first surface extending in the common plane of the outlet openings of the pressure chamber members and having corresponding passages aligned therewith and extending through the manifold member and having a second surface formed with ink passages extending from the corresponding passages toward and terminating in a common line extending along the second surface.

13. An ink jet head according to claim 12 including an orifice plate affixed to the second surface of the manifold member and having a linear array of orifices aligned with the common line to receive ink from the ink passages formed in the second surface.

14. An ink jet head according to claim 13 wherein each orifice in the orifice plate has a cylindrical nozzle opening at the outlet end, a larger diameter cylindrical inlet opening at the inlet end, and a tapered conical section extending between the inlet opening and the nozzle opening.

15. An ink jet head according to claim 14 wherein the cylindrical inlet opening has a diameter which is no more than about twice the diameter of the cylindrical nozzle opening and has a length at least as long as that of the nozzle opening.

16. An ink jet head according to claim 15 including an ink reservoir affixed to the carbon collar and an ink passage formed in the collar member, the manifold member and the pressure chamber members to supply ink to the pressure chambers in the pressure chamber members.

17. An ink jet head according to claim 16 including a heater disposed at least in part in the collar member.

18. An ink jet head according to claim 11 wherein the arrays of internal passages terminate in a common plane at a further surface of the pressure chamber member and including a carbon manifold member formed with arrays of internal ink passages corresponding to the arrays of internal ink passages in the pressure chamber member and having a first surface engaging the further surface of the pressure chamber member, and retaining means for releasably retaining the first surface of the manifold member and the further surface of the pressure chamber member in engagement with the corresponding arrays of internal passages therein maintained in alignment.

19. An ink jet head according to claim 18 wherein the manifold member has a second surface formed with passages extending from the arrays of internal passages therein toward and terminating in a common line extending along

the second surface, and an orifice plate affixed to the second surface of the manifold member having a linear array of orifices with axes intersecting the common line on the second surface of the manifold member.

20. An ink jet head according to claim 19 wherein each of the orifices in the array has a cylindrical nozzle opening at the outlet end and a larger diameter inlet opening at the inlet end and a tapered conical section extending between the inlet opening and the nozzle opening.

21. An ink jet head according to claim 20 wherein the cylindrical inlet opening has a diameter which is no more than about twice the diameter of the cylindrical nozzle opening and has a length at least as long as that of the nozzle opening.

22. An ink jet head according to claim 1 including a tubular member made of air-permeable, ink-impermeable material disposed within the ink passage and connected to a source of subatmospheric pressure.

23. An ink jet head according to claim 22 including porous support means disposed within the tubular member.

24. An ink jet head according to claim 1 including a heater disposed in heat-transmitting relation to the carbon member.

25. An ink jet head comprising an orifice plate having orifices through which ink is selectively ejected, a carbon plate formed with orifice passages to supply ink to the orifices in the orifice plate and formed on one side with pressure chambers communicating with the orifice passages and formed with ink supply passages leading to the pressure chambers, and a piezoelectric plate having one side affixed to the side of the carbon plate in which the pressure chambers are formed and provided on its opposite side with an electrode pattern corresponding to the pattern of pressure chambers in the carbon plate.

26. An ink jet head according to claim 25 wherein the orifice plate is affixed to the side of the carbon plate opposite from the piezoelectric plate and including flowthrough passages formed on the side of the carbon plate adjacent to the orifice plate leading from the orifice passages to the ink supply passages.

27. An ink jet head according to claim 25 wherein the carbon plate has an edge in which the orifice passages are formed and wherein the orifice plate is affixed to the edge of the carbon plate containing the orifice passages.

28. An ink jet head according to claim 28 wherein the carbon plate is about 1020% porous.

29. An ink jet head according to claim 25 including a thin layer of epoxy adhesive between the piezoelectric plate and the carbon plate.

30. An ink jet head according to claim 25 including a heating element formed on the surface of the piezoelectric plate.

31. An ink jet head according to claim 25 including a thin layer of epoxy adhesive between the orifice plate and the carbon plate.

32. An ink jet head according to claim 25 including a plurality of sets of orifice passages in the carbon plate and a plurality of separate ink supply passages for supplying different colored ink to each set of orifice passages.

33. An ink jet head according to claim 25 including deaeration means for deaerating ink in the ink jet head.

34. An ink jet head according to claim 33 wherein the deaeration means includes an air-permeable, ink-imperme-

able layer adjacent to an ink flowpath in the ink jet head and a vacuum source communicating with the air-permeable, ink-impermeable layer.

35. An ink jet head according to claim 34 wherein the carbon plate is porous and wherein the vacuum source communicates with the air-permeable, ink-impermeable layer through the porous carbon plate.

36. An ink jet head according to claim 35 wherein the air-permeable, ink-impermeable layer is a coating on the surfaces of passages formed in the carbon plate.

37. An ink jet head according to claim 35 wherein the air-permeable, ink-impermeable layer is a membrane disposed between a portion of the carbon plate and an adjacent ink passage in the ink jet head.

38. An ink jet head according to claim 37 wherein the adjacent ink passage is formed in a further plate affixed to the carbon plate.

39. An ink jet head according to claim 34 wherein the orifice plate is affixed to one side of the carbon plate and including flowthrough passages formed on the side of the carbon plate adjacent to the orifice plate leading from the orifice passages to the ink supply passages to permit circulation of ink through the passages and through the deaeration means.

40. An ink jet head according to claim 39 including heater means formed on the piezoelectric plate to heat ink in the passages in the carbon plate and produce thermal convective circulation thereof through the passages and the deaeration means.

41. An inkjet head according to claim 25 including a plurality of piezoelectric plates affixed in adjacent relation to the pressure chamber side of the carbon plate.

42. An ink jet head according to claim 41 wherein the orifice passages are formed in an edge of the carbon plate and including further passages extending between the orifice passages and the corresponding pressure chambers.

43. An ink jet head according to claim 25 wherein the orifice passages are formed in an edge of the carbon plate and including passages extending perpendicular to the orifice passages and the pressure chambers to connect the pressure chambers to the orifice passages.

44. An ink jet head according to claim 25 wherein the carbon plate has a projecting portion containing the orifice passages and extending away from the side of the plate opposite from the pressure chambers.

45. An ink jet head according to claim 25 including a coating of a material having a high modulus of rigidity on the surfaces of the pressure chambers formed in the carbon plate.

46. A method for making an ink jet head comprising forming a carbon plate with a plurality of orifice passages, with a plurality of pressure chambers communicating with the orifice passages, respectively, and with an ink supply passage leading to the pressure chambers, affixing a piezoelectric plate to one side of the carbon plate so that a pattern of actuating electrodes is provided adjacent to the corresponding pressure chambers, and affixing an orifice plate having ink jet orifices to the carbon plate so that the orifices are aligned with the orifice passages in the carbon plate.

47. A method according to claim 46 including affixing the piezoelectric plate to the carbon plate with epoxy adhesive.

48. A method according to claim 46 including affixing the orifice plate to the carbon plate with epoxy adhesive.

49. A method according to claim 46 including forming the plurality of orifices in the orifice plate by electrical discharge machining.

50. A method according to claim 46 including affixing a piezoelectric plate having a conductive coating on the exposed surface to one side of the carbon plate and forming the actuating electrodes on the exposed surface of the piezoelectric plate by photoetching the conductive coating.

51. A method for making an ink jet head comprising affixing a piezoelectric plate having an exposed conductive surface to a surface of an adjacent plate having a pattern of pressure chambers formed therein and photoetching the conductive coating on the piezoelectric plate to produce an electrode pattern conforming to the pattern of pressure chambers in the adjacent plate to which the piezoelectric plate is affixed.

52. A method according to claim 51 wherein the piezoelectric plate is affixed to the surface of the adjacent plate by spraying one of the surfaces of the plates with a thin layer of epoxy adhesive.

53. A method according to claim 51 wherein the photoetching step is carried out by applying a layer of photoresist to the conductive coating, subjecting the photoresist to a radiation pattern, developing the photoresist, and etching the conductive layer in the region exposed by the developed photoresist.

54. A method of forming a plurality of ink jet head components comprising forming a plurality of patterns of orifice passages, pressure chambers and ink supply passages at a plurality of locations in a carbon plate, applying a plurality of piezoelectric plates having conductive coatings on the exposed surfaces thereof to one surface of the carbon plate, and photoetching the conductive coatings on the piezoelectric plates to produce patterns of electrodes corresponding to the patterns of pressure chambers formed in the carbon plate.

55. A method according to claim 54 including separating the carbon plate into a plurality of plate portions, each including one of the piezoelectric plates.

56. A method for making an ink jet head comprising forming a pattern of orifice passages, pressure chambers and ink supply passages in a porous carbon plate and coating the passages in the plate with an air-permeable, ink-impermeable layer.

57. A method according to claim 56 including affixing a piezoelectric plate to one side of the carbon plate adjacent to the pressure chambers formed therein, affixing an orifice plate having orifices aligned with the orifice passages to a surface of the carbon plate containing the orifice passages, and providing an exposed surface of the porous carbon plate for communication with a vacuum source.

58. A method for poling a piezoelectric plate comprising compressing a piezoelectric plate between electrode plates with a slightly conductive rubber sheet interposed between each electrode plate and the piezoelectric plate.

59. A method for poling a piezoelectric plate comprising applying one surface of a piezoelectric plate to a ground plate and applying electric charge from a corona discharge device to the opposite surface of the piezoelectric plate.

60. An orifice plate for an ink jet head comprising a metal plate having an array of orifices wherein each of the orifices has a cylindrical nozzle ink outlet portion at one side of the plate, a cylindrical ink inlet portion at the opposite side of

the plate having a larger diameter than the nozzle portion, and a tapered conical portion joining the inlet portion and the nozzle portion.

61. An orifice plate according to claim 50 wherein the diameter of the inlet portion is no more than about twice the diameter of the nozzle portion.

62. An orifice plate according to claim 60 wherein the length of the inlet portion is greater than the length of the nozzle portion.

63. A deaeration member for an ink jet head comprising a tubular member made of air-permeable, ink-impermeable material and adapted to be inserted into an ink passage in an ink jet head, one end of the tubular member being sealed and the other end of the tubular member being connectable to a source of subatmospheric pressure.

64. A deaeration member according to claim 63 wherein the tubular member is made of polytetrafluoroethylene.

65. A deaeration member according to claim 63 including a porous support member disposed within the tubular member.

66. A deaeration member according to claim 63 wherein the tubular member has a 0.1 mm wall thickness and a 1.5 mm diameter.

67. An ink jet head comprising an orifice plate having an array of ink jet orifices, a manifold plate affixed to the orifice plate and having spaced arrays of ink passages extending

through the manifold plate and arrays of passages in the surface of the manifold plate adjacent to the orifice plate which communicate with the orifices in the orifice plate.

68. An ink jet head according to claim 67 including a pressure chamber plate having an array of pressure chambers formed in a first surface and a corresponding array of internal ink passages leading from the pressure chambers to a second surface, and retaining means for retaining the orifice plate, the manifold plate and the pressure chamber plate in assembled relation with the passages therein arranged to provide communication between each of the pressure chambers and a corresponding orifice.

69. An ink jet head according to claim 68 including a collar member assembled to the pressure chamber plate and the manifold plate and an ink passage formed in the pressure chamber plate, the manifold plate and the collar member to supply ink to the pressure chamber plate from a reservoir connected to the collar member.

70. An ink jet head according to claim 68 including a filter member disposed between the second surface of the pressure chamber plate and the manifold plate.

71. An ink jet head according to claim 68 wherein the retaining means comprises screws.

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