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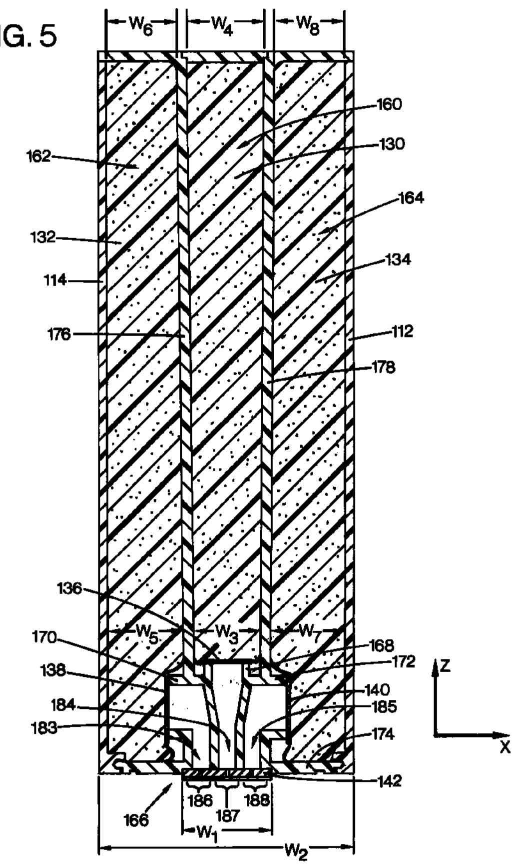
(54) Ink-jet pen with capillarity gradient

(57) Disclosed is a novel ink jet pen (22,24,276,296) in which polyurethane foam (130,132,134,284,302) is used for ink containment and backpressure. The disclosed pen has a gradually increasing compression of the foam from the bottom of the ink chamber (22,24,276,296) to the top. The increasing compression of the foam results in increased capillarity, which tends to offset the pressure, or gravity head, due to the column of ink when the pen is full. As ink is depleted from the foam during printing, the gravity head is reduced, but so is the effect of the increased capillarity of the foam near the top of the pen, since the ink is no longer in this region. The pen has a more even level of backpressure over the life of the pen, resulting in more uniform droplet size and a corresponding improvement in print quality.

FIG. 5



EP 0 709 210 A1

Description

BACKGROUND OF THE INVENTION

Field of the invention

The present invention is directed to device and method for storing ink for use in ink-jet printing, and is particularly directed to an ink chamber having a porous member that has an increasing capillarity from its bottom toward its top to offset the gravity head due to the ink column in the chamber.

Description of the Related Art

Ink-jet printers commonly use replaceable print cartridges, referred to as "pens." Ink jet pens typically include a printhead and an ink chamber filled with a supply of ink. The printhead is a sophisticated micromechanical part that contains an array of small firing chambers that are energized to "jet" small droplets of ink out of an array of nozzles on the printhead. Typical printheads employ either thermal resistors or piezoelectric transducers to accomplish the jetting action. The pen is locked into a carriage in the printer, where the pen electrically interfaces with the printer. The printer scans the carriage and pen back and forth across the print medium (e.g., paper) as the pen ejects small droplets of ink from the nozzles in selected patterns. After each swath of printing, the printer advances the medium incrementally one swath width to begin a new swath. Successive swaths are printed in this manner to print the desired alphanumeric characters or graphics on the medium.

The ink in the pen must be held in the ink chamber at less than atmospheric pressure, so that it does not drool out of the nozzles when the nozzles are not firing. However, this negative relative pressure, or backpressure, must not be so great that air is gulped into the interior of the firing chambers, thereby causing them to deprime and no longer function.

It has become increasingly important to make ink-jet pens as narrow as possible. The overall width of the pen influences the width of the printer and the amount of desk space the printer takes up. In addition, when printing with multiple pens, such as in color printing, print quality can be enhanced by making the pens narrower, because the narrower pens allow the printheads of the pens are more closely spaced in the scanning direction. On the other hand, users of printers desire that ink-jet pens last longer, in other words, that they hold more ink. Therefore, the designer of ink-jet pens must deal with the competing demands of making the pens narrower, and the need to increase the volume of ink contained in the pen.

One way of increasing the volume of ink while maintaining a narrow profile is to make the pen taller. However, when the pen is fill of ink, the column of ink in each chamber tends to exert a certain pressure on the ink at the bottom of the chamber due to gravity. This gravity pressure or head is approximately proportional to the height of this column of fluid. Therefore, when the chambers are fill of ink, this head of liquid tends to counteract the desired backpressure of the ink in the foam. It is preferable, however, to maintain the backpressure of the fluid at a relatively constant level throughout the life of the pen to provide a more constant droplet size, which results in improved print quality.

One of the most reliable backpressure systems uses a porous material, such as synthetic foam, in the ink tank. Ink is injected into the foam and the foam retains the ink at the appropriate backpressure by capillary action. US Patent No. 4,771,295 (Baker '295), which is assigned to Hewlett-Packard Company (the assignee of the present invention), discloses an ink-jet pen that uses synthetic foam for ink retention and backpressure. A key feature of the pen disclosed in Baker '295 is an ink pipe that extends upward from a bottom wall of the pen body and into compressive contact with the foam. The ink pipe is the fluid conduit for the ink from the foam to the printhead, and also serves an important function of locally compressing the foam to thereby locally increase the capillarity of the foam in the region of the ink pipe. As ink is depleted from the foam, the increased capillarity near the ink pipe tends to draw ink from all other portions of the foam toward the ink pipe, so that the maximum amount of ink can be drawn from the foam for printing.

French patent document publication no. 2,229,320 to Claude Barta discloses the use of foam for ink retention in a pen plotter. The inking device has an ink reservoir that encloses a compressible cellular material, such as polyurethane foam. The foam is compressed by a convex-shaped wall extending into one side of the foam so that the foam is increasingly compressed, with the maximum compression at an opening formed in the wall. The opening forms the orifice of a duct leading to a plotter pen tip. This increased compression and the resultant increased capillarity of the foam tends to attract, by capillary action, the ink toward the conduit, and hence to the plotter pen tip.

European patent application 139 508, listing as inventors Takashi Suzuki et al., discloses a porous member for ink containment in a wire dot printer. The porous member has a roughly trapezoidal cross section before insertion into the ink tank, with one side of the foam having a greater thickness than the other. The ink tank has a roughly rectangular cross section, so that once inserted, the regions of the foam having the greatest thickness before insertion are the most compressed and therefore have the greatest capillarity. The high-capillarity regions are adjacent to an ink supply guide. The ink is attracted to the printing wire by grooves having successive increasingly smaller dimensions and corresponding increases in capillarity. This reference also discloses another embodiment that uses two separate slabs of porous material having different average pore sizes, with the smaller-pore sized foam closest to the ink supply guide.

While the above-cited references teach the use of compression to attract ink in a desired direction by capillary action, they do not deal with the problem of the gravity head in the ink chamber. These references all disclose relatively short pens, in which the gravity head problem is not a great factor. There remains a need for an ink containment mechanism for ink jet printers that allow for taller ink chambers with higher volumes of ink, and yet which does not introduce additional problems associated with the increased gravity head resulting from the column of ink in the chamber.

SUMMARY OF THE INVENTION

The present invention provides an ink storage device and method for an ink-jet printing system The storage device is oriented in the printing system to have a top and a bottom as considered in a gravitational reference frame and comprises an ink chamber and a porous member inserted in the ink chamber. The porous member has a generally increasing capillarity from the bottom of the ink chamber toward the top of the ink chamber. Stated another way, the porous member has a generally increasing capillarity along its height extending away from its bottom. A body of ink is stored in the porous member. The ink storage device may be formed as part of an ink-jet pen, having an attached printhead. A plurality of such storage devices may be used as part of a multiple-chamber ink-jet pen.

A gravitational reference frame means simply that words like "top," "bottom," "height," and "upward" etc. are taken in their common usage with relationship to the earth. The "top" of something is farther away from the earth than the "bottom." "Upward" means away from the earth. The "height" of something is its measurement along a direction away from the earth.

The invention also provides a process of passing ink to an ink ink-jet printhead. This process, comprises the following steps: filling ink into a synthetic foam having a top and a bottom as considered in a gravitational reference frame, the foam having a linearly increasing capillarity from its bottom toward its top; and passing the ink from the foam to the printhead with a controlled capillary force.

The invention allows for ink containment in ink-jet printing systems that provide for a more constant backpressure during the depletion of ink from the chamber, thereby allowing for a more constant ink droplet volume and improved print quality. The increased capillarity of the porous member in the direction toward the top or extending along the height away from the bottom provides additional capillary attraction to the ink in the porous member when the ink is in the upper regions of the ink chamber, i.e., when the pen is full. This increased capillarity offsets to a certain extent the gravity head developed due to the column of ink in the ink chamber. A more even level of backpressure is thus obtained.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective, partial cut-away view of a printer employing an ink-jet pen of the invention.

FIG. 2 is a perspective view of pen 24 of FIG. 1.

FIG. 3 is a side view of pen 24.

FIG. 4 is an exploded view of pen 24.

FIG. 5 is a sectional view of the main body member 110 taken along lines 5-5 of FIG 3 as viewed to the left in FIG. 3.

FIGS. 6 and 7 are side views of a felting mechanism for foam members.

FIG. 8 illustrates sequential steps for forming a low-friction cover sheet 230 for the center foam member 130.

FIG. 9 is a graph of the backpressure curve for the center chamber 160.

FIG. 10 is a graph of the backpressure curve for the side chambers 162 and 164.

FIGS. 11 and 12 illustrate a process for forming an alternate embodiment 234 for the center foam member 130.

FIG. 13 is a perspective view of a filling mechanism.

FIG. 14 is an exploded sectional view of a single chamber pen of the invention.

FIG. 15 is an exploded sectional view of another embodiment of a single chamber pen of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1 illustrates an ink-jet printer that uses a pen of the invention. The printer is illustrated only schematically, and paper input trays, paper output trays and other options are not illustrated. The printer, generally indicated at 10, includes a housing 12, carriage 14, controller 16, carriage drive motor 18 and paper drive motor 20. A monochrome black pen 22 and a multi-chamber three-color pen 24 are mounted in carriage 14 as shown. A print medium 26 is shown in printer 10 to be printed on by pens 22 and 24. Print medium 26 may be, for example, paper, transparency film, envelopes, or other print media.

Printer 10 activates pens 22 and 24 to print upon print medium 26 in a manner well known in the art, but briefly described as follows. Carriage advance motor 18 is linked to carriage 14 by means of belt 28. Controller 16 activates carriage advance motor 18 to drive carriage 14 to the right or to the left in the scanning direction as indicated by the arrow marked X. Each time carriage 14 moves to the right or to the left, the printer prints a "swath" on medium 26. Media advance motor 20 is connected to gearing mechanism 30 (schematically illustrated). Gearing mechanism 30 is connected to drive rollers and pinch rollers (not shown), which in turn directly interface with the medium 26 in a manner well known in the art.

After carriage 14 has completed one swath of printing, controller 16 activates media advance motor 20 to move the medium 26 one swath width in the direction marked Y, which is the media-advance direction. After another swath is completed, the medium 26 is advanced another swath width in direction Y so that another swath may be printed. In this manner, successive swaths are printed until all of the desired alphanumeric characters and/or graphics are printed on medium 26.

The area of medium 26 that is being printed upon may be referred to as the print zone, marked A. The print zone A may be considered to be the current swath width area that is being printed upon as carriage 14 scans across medium 26. The width of various components of pens 22 and 24 are measured in the scanning direction X. The length of components of pens 22 and 24 are measured in the media-advance direction Y. The height of pens 22 and 24 is measured in the direction marked Z, which is normal to the print medium 26 at the print zone A.

As shown in FIGS. 2 and 3, multi-chamber pen 24 includes a main body member 110, side cover members 112 and 114, center cover member 116, finger tab 118, and a flex strip 120 containing contact pads 122. The finger tab 118 is included to allow the user to more easily insert the pen 24 into the printer carriage 14 as shown in FIG. 1. The main body member 110 of pen 24 is divided mainly into two parts, the main ink cavity portion 124 and the nose portion 126.

As shown in FIG. 4, the multi-chamber pen 24 also includes center porous member 130, side porous member 132, side porous member 134, center filter 136, side filters 138 and 140, and printhead 142. Printhead 142 is attached to main body member 110 by means of a heat curable epoxy layer 144. Flex strip 120 is heat staked to main body member 110. Flex strip 120 is a custom-made tape automated bonding (TAB) circuit formed of a polymer film with custom designed copper traces that connect to contact pads on the printhead. An adhesive layer 146 of thermoplastic bonding film is laminated to flex strip 120 before it is heat staked to the main body member. Adhesive layer 146 melts and aids the bonding of flex strip 120 to the main body member and helps provide electrical insulation for the conductors on the flex strip. Custom-made TAB circuits are commonly available and widely used in the electronics industry. The printer into which the pen 24 is inserted interfaces with contact pads on flex strip 120 to provide the appropriate driving signals to cause the resistors on the printhead to fire at the appropriate time.

Filters 136, 138 and 140 are attached to main body member 110. A threaded nylon plug 146 is pressed into hole 148 formed in center cap 116. Likewise, threaded nylon plugs 150 and 152 are pressed into holes 154 and 156 formed in main body member 110. The helical thread pattern on these plugs provides an air path to allow the pen to breathe in air as ink is depleted from the foam members 130, 132, and 134. The long narrow channel of this helical pattern acts as barrier to vapor diffusion from the inside of the pen to the ambient environment.

Foam member 130 is inserted into center chamber 160 of main body member 110. Foam member 132 is inserted into side chamber 162, and foam member 134 is fitted into side chamber 164. Foam members 130, 132, and 134 are preferably formed of a polyether based polyurethane open cell foam without anti-oxidant. Other porous materials may also be used, such as innately reticulate thermoset melamine condensate. After the foam members are inserted into the main body member, cover members 114, 112, and center cover member 116 are ultrasonically bonded to the main body member 110 to enclose the foam members 130, 132, and 134 within the pen. Once the step of bonding cover members 112, 114, and 116 is complete, ink is injected into foam members 130, 132, and 134.

Main body member 110 is formed as a single unitary part to include the previously described center chamber 160, and side chambers 162 and 164. Main body member 110 includes a manifold section 166, which channels the ink from the ink chambers 160, 162, and 164 toward the printhead. Main body member 110, as with other portions of the pen body, is made of glass filled PET (polyester) with a 15% glass fill.

Manifold 166 includes a center ink pipe 168 and two side ink pipes 170 and 172. Ink pipe 168 extends upward from bottom wall 174 and ink pipes 170 and 172 extend outward from sidewalls 176 and 178. Ink pipes 168, 170 and 172 form ink inlets to receive ink from their respective ink chambers. These ink pipes have rectangular cross sections with dimensions of 9.6 mm by 4.5 mm, and thus have internal cross-sectional areas of 43.2 mm^2. Filter 136, which is formed of stainless steel wire mesh is heat staked to center ink pipe 168, as shown. Similarly, stainless steel wire mesh filters 138 and 140 are heat staked to side ink pipes 170 and 172, as shown. These filters have the same effective filtering area as the ink pipes to which they are attached, i.e., 43.2 mm^2. They have a nominal filtration capability of about 15 microns and a typical thickness of about 0.15 mm.

These filters preclude debris and air bubbles from passing from the foam into the ink pipes. They also provide an important function in preventing spiked surges of ink through the filter. The spaces between the wire strands act as fluid restrictors, which resist fluid flow based on an exponential relationship to the velocity of fluid passing through the filter. Thus, if ink is traveling slowly through the filters, for example during printing, nominal resistance is met at the filter. Without the filter, if the pen were to be jarred, for example, by being dropped, any surges in the ink could easily cause air to be gulped into the firing chambers of the printhead, causing these chambers to deprime. However, with the filter in place, rapid fluid flow through the filters is largely prohibited, so that gulping does not occur.

As shown in FIG. 5, center foam member 130 is inserted into center chamber 160 from the Z direction to be compressed by center ink pipe 168 and filter 136. Center foam member 130 compresses down over and extends around the perimeter of ink pipe 168 and filter 136, as shown. This compression and overlap of foam member 130 around the perimeter of ink pipe 168 and filter 136, because of frictional engagement, greatly inhibits any motion of foam member 130 in any direction normal to the Z direction. Similarly, foam member 132 is inserted into side ink chamber 162 from the X direction shown in FIG. 5 to be compressed by and to conform around the perimeter of side ink pipe 170 and filter 138. Foam member 134 is inserted into ink chamber 164 from the X direction to be compressed by and to conform around the perimeter of ink pipe 172 and filter 140, as shown. The compression of foam members 132 and 134 by their respective ink pipes and filters and their frictional engagement of the perimeter of the ink pipes and filters greatly inhibits any motion of foam members 132 and 134 in any direction normal to the X direction.

The compression of foam members 130, 132, and 134 by their respective ink pipes and filter increases the capillarity of the foam members in the region of their respective ink pipes and filters. This capillarity increase causes ink to be attracted toward the ink pipes 168, 170, and 172. From these conduits, the ink is fed to the back side of printhead 142 from which it can be jetted onto the print medium according to signals received from the printer.

Printhead 142 is based on a substrate formed from an electronics grade silicon wafer. The resistors, conductors, ink channel architecture, and other printhead components are formed on the substrate using photolithographic techniques similar to those used in making integrated circuits. Printhead 142 is a face-shooter design, which means that the ink is fed to the substrate from a position behind the substrate, and the droplets are ejected normal to the substrate surface. Because the ink is fed to the back side of the printhead, the natural orientation of the ink pipe in face-shooter printheads is normal to and pointing away from the print medium and orthogonal to the scanning direction. One advantage of bringing the ink to the printhead surface from the back side is that the ink contact with the printhead can act as a heat sink to remove heat from the printhead as printing progresses.

As can be seen, the width W1 of the printhead 142 is significantly smaller than the width W2 of the entire pen. As has been stated, minimizing the size of the printhead is important in minimizing the overall cost of the pen because of the relatively expensive components in the printhead. It is also apparent that the only ink-to-ink interface between inks of different colors occurs at the back side of the printhead 142. Specifically, adhesive layer 144 keeps the inks of different colors apart. Thus, even though pen 24 carries a relatively large volume of ink and has a relatively small printhead, the manifold feature 166 allows the printhead to have only one ink-to-ink interface. In other words, there are no seams or other connections at other positions in the printhead where ink of one color might leak into a chamber dedicated to another color. This beneficial feature of having only one ink-to-ink interface is accomplished because of the novel manifold 166 being formed as part of the main body member 110. Thus, an ink-to-ink interface is eliminated as compared to previous-generation multi-color HP pens, in which the region of attachment of the ink chamber cover member provided an additional ink-to-ink interface, with the inherent risk of ink mixing.

The center chamber 160 is defined by the space between sidewalls 176 and 178 and extending upwardly from bottom wall 174. The side chambers 162 and 164 are defined to be on the outside of sidewalls 176 and 178 respectively. Ink pipe 168 extends upwardly from bottom wall 174 and into compressive contact with the center foam member 130. Inward walls 176 and 178 extend upwardly from bottom wall 174. Ink pipes 170 and 172 extend outwardly from inward walls 176 and 178, respectively, and into compressive contact with the respective foam members 132 and 134, as shown. Manifold 166 has three ink outlets, 183, 184, and 185. Printhead 142 has three groups of nozzles, 186, 187, and 188. As can be seen, center ink pipe 168 fluidically communicates with center ink outlet 184, and thus with the center group of nozzles 187. Side ink pipe 170 fluidically communicates with ink outlet 183 and hence with nozzle group 186. Side ink pipe 172 fluidically communicates with outlet 185 and hence with nozzle group 188.

It is important that ink pipes 168, 170, 172 extend into compressive contact with the foam to increase the capillarity of the foam in the region of the ink pipes. The filters 136, 138, and 140 also serve an important role in assisting in this compression. In the previous-generation pens produced by the assignee of the present invention, discussed above, these ink pipes extend upwardly, all in the same direction, from a bottom wall of the pen. These ink pipes are all oriented in the same direction, upwardly and away from the bottom wall of the pen. However, in the illustrated pen of the present invention, only one of the ink pipes, ink pipe 168, extends upwardly away from the bottom wall 174. The other two ink pipes, 170 and 172 extend outwardly into their respective ink chambers.

The dimensions of the pen 24 are given in Table 1, below. These dimensions are given for the main ink cavity portion 124 and ignoring the nose portion 126 (FIG. 3). For the portions of pen 24 described, the width is taken along X axis, length is taken along the Y axis, and height is taken along the Z axis. As shown in FIG. 5, center chamber 160 has a bottom width W3 and a top width W4. Chambers 162, 164 have bottom widths W5, W7 and top widths W6, W8 respectively. All dimensions are given in millimeters except where indicated. Sidewalls 176 and 178 each have a 1% draft angle toward the outside of the pen, so that the width of chambers 162 and 164 decreases on a 1% grade from the bottom toward the top.

Table 1

Pen 24 Dimensions						
	Bottom Width	Top Width	Bottom Length	Top Length	Height	Volume (cc's)
Center Chamber 160	8.05	10.29	56.64	57.73	68.07	35.71
Side Chambers 162 and 164	9.83	8.64	55.75	55.75	70.01	36.04

The following Table 2 compares the height of the three ink chambers 160, 162, 164 against their respective widths. Since the three chambers each have differing widths along their height, the height/ width comparisons are made for the bottom width, top width, and average width of each chamber.

Table 2

Pen 24 Dimension Ratios						
	height/width ratios			length/width ratios		
	bottom	top	average	bottom	top	average
Center chamber 160	8.46	6.62	7.42	7.03	5.61	6.24
Side Chambers 162 and 164	7.12	8.10	7.58	5.67	6.45	6.04

Thus the height/width ratios are all at least 6, with most of them at least 7. They range from about 6-1/2 to about 8-1/2. The height/width ratios using the average widths of the chambers are all at least 7, and are close to about 7-1/2. The length/width ratios are all at least 5. They range from about 5-1/2 to about 7. The length/width ratios using the average widths of the chambers are all in about the 6 to 6-1/4 range.

The dimensions and dimension ratios of the chambers of pens 24 can be compared to corresponding values of previous-generation pens produced by Hewlett-Packard Company, the assignee of the present invention. The following Table 3 gives the dimensions and key dimension ratios of previous-generation HP pens, as identified by their commonly known and widely used model numbers.

Table 3

Previous-Generation HP Pens					
	Cavity Size			Cavity Ratios	
Pen Type	width	height	length	ht/wid	In/wid
51606A (PaintJet black)	22.6	32.8	31.4	1.45	1.39
51606A (PaintJet color)	6.8	33.0	32.8	4.89	4.86
51608A (DeskJet black)	25.3	41.2	34.3	1.66	1.36
51625A (DeskJet color)	14.2	42.0	25.6	2.96	1.80

As indicated in Table 3, DeskJet 51608A color pens have a height/width ratio 2.96 and the length/width ratio is 1.80. A question that must be resolved, however, is what is the "width" of the chambers in the 51625A DeskJet color pen. For the purposes of the above tables, the narrowest dimension, which is in the media-advance direction, is selected as the width dimension. If the dimension along the scanning direction (when the pen is installed in the printer) is chosen as the width, then the width and length measurements would be interchanged in the above tables. The chambers in the 51625A color pens are narrower in the paper-advance direction because they are transversely oriented, or arranged side by side in the paper-advance direction, rather than in the scanning direction. This transverse orientation creates the need for a complicated manifold to duct the ink from the ink chambers to the printhead. This manifold must be formed as a separate part and attached, e.g., by adhesive or ultrasonic weld to the bottom of the pen. The manifold thereby introduces undesirable additional ink-to-ink interfaces between inks of different colors at locations where pen parts are attached to each other.

PaintJet 51606A color pens have a height/width ratio of 4.89 and a length/width ratio of 4.86. Thus, the PaintJet color pen chambers have close to a square cross section as viewed from the side, and may be considered as having a narrow aspect ratio. PaintJet color pens avoid the problem of multiple ink-to-ink interfaces between pen body parts in the region of the printhead. However, these pens have the undesirable trait of having a very wide printhead. This wide printhead is expensive and also places the nozzles groups corresponding to the three colors farther apart than is desirable for improved print quality.

It is significant to note that the height/width ratio of the pen 24 chambers are between 35 to 73% greater than the height/width ratio of the PaintJet color chambers. In terms of absolute height, the height of the pen 24 chambers is about 70 mm (excluding the nose portion 126); whereas the height of the PaintJet color chambers is just 33 mm. Therefore, the pen 24 chambers are more than twice as tall as the PaintJet color pen chambers.

Previous HP foam-based pens have the ink pipe extending upward into the foam from a bottom interior wall of the pen. This upward orientation, normal to the printhead surface and to the print medium is the natural orientation for the ink pipe in face-shooter pens. However, because of the absolute height of pen 24 and its height/width aspect ratio, loading the foam into the ink chambers from the top would be difficult without introducing wrinkling or other anomalies in the foam that cause stranding of ink.

Pen 24 also has narrow aspect ratio ink chambers, since it has both a height/width or length/width ratios of 4 or more. Even though the ink chambers in pen 24 have narrow aspect ratio ranges as indicated in Table 2, the foam members are loaded into their respective chambers 160, 162, and 164 without introducing the above-mentioned problems associated with narrow aspect ratio ink chambers. This is true because of various factors. First, the foam members are highly felted, which provides these foam members enhanced stiffness. In addition, the foam members are felted to have final dimensions close to the interior cavity dimensions of their respective chambers. (Felting is discussed more completely in reference to FIGS. 6 and 7.) In center chamber 160, which must be loaded top down, the chamber has a greater width near its top than near its bottom, so that the walls of the chamber increasingly compress the foam as it is loaded.

Finally, the outer chambers 162 and 164 of pen 24 open to the side, rather than from the top, and the foam members 132 and 134 are loaded from the outward side. This produces the result that foam members 132 and 134 only need to be loaded over a very small distance (about 9 mm) into the pen body before they in compressive contact with their ink pipes. Therefore, problems related to foam insertion, such as ink stranding and uncertain contact with the ink pipe, are minimized.

An important issue that must be considered is the molding process that must be used to form the pen body parts. Ink-jet pen bodies are typically formed of injection molded plastic. The chambers of the previous generation HP foam-based pens have their ink pipes extending upward from the bottom of the chambers and are formed to have the foam inserted from openings from the top of the chambers. These chambers are therefore formed as deep interior cavities. To form such a deep cavity, a molding part must extend deeply into the plastic part being molded. In the case of three-chambered pens, there must be three such mold parts closely spaced side by side. After the plastic is injected into the mold and around the molding parts to form the pen body, the deep mold sections must be removed from the ink chambers. The greater the height/width and/or length/width ratios are, the more difficult it is to remove these mold sections without damaging the molded part. If all three of the chambers in pen 24 were formed as deep cavities so that the foam was inserted from the top down, the molding assembly would be very difficult to design, if indeed possible at all, because of the difficulty in removing interior molding parts from three such deep, side-by-side chambers.

Center chamber 160 is formed as a deep cavity. However, the problems with such deep chambers are solved to some degree in the center chamber by forming the center chamber to have an increasing width from the bottom toward the top. Since the exterior of the pen has a generally rectangular shape, the outside chambers must therefore have a decreasing width from the bottom toward the top. Thus, it is feasible to have one chamber (the center chamber) have such an increasing width, but it would not be feasible to have all three chambers have such an increasing width, unless the pen had a non-rectangular outer form factor, or if the walls of the pen were of non-uniform wall thickness. Either of these alternatives are undesirable.

Before foam body members 130, 132, and 134 are inserted into pen 24, they must be "felted." As stated, foam body members 130, 132, and 134 are preferably formed of reticulated polyurethane foam. Felting is a process in which foam is subjected simultaneously to heat and compression, which causes the foam to take a set and retain its compressed state. The felting process is described in reference to FIGS. 6 and 7. Before felting, the foam has an average pore size of 85-90 pores per inch, a density of about 1.3 lbs. per cubic foot, and a thickness of about 2.3 inches.

In FIGS. 6 and 7, two felting presses 210 and 212 are used to felt a reticulated polyurethane foam member 214. As shown in FIG. 7, the felting presses 210 and 212 are brought closer together to compress foam member 214. At the same time, heat is applied through felting presses 210 and 212, which causes the internal structure of foam member 214 to take a set and to retain its compressed configuration shown in FIG. 7. The foam is felted at 360° F for 35 minutes. After felting, the foam has a thickness of about 0.42 inches. Thus, as compared to their uncompressed state as shown in FIG. 7, the foam body members 130, 132, and 134 are felted a total of 548% before insertion into the pen body. Stated another way, the foam is felted to about 18% of its pre-felted state. The foam used in pen 24 has a significantly higher felting than previous-generation HP pens.

A large slab of foam is felted, and the foam members are cut from this slab. Foam members may be either cut with saws or die stamped. Die stamping is preferred because it is more efficient and less expensive. Felting makes the foam bodies much easier to die stamp because the felted foam is stiffer and resists rolling around the edges during the stamping process. If the foam is not felted, it is not as stiff, and the edges roll excessively during the stamping process. Even if the foam body is felted and die stamped, it is preferable to do a finishing step of sawing certain edges of the foam body to make them more square, particularly the edges parallel to the Z axis as shown in FIG. 4, such as edges 218, 220, 222, and the other vertical edge not shown.

A benefit of the felting process is that it aids in the insertion of the foam members into the pen body. This is particularly true of the center foam member 130. The felting process makes the foam more stiff in the Z direction as viewed in FIGS. 4 and 6. The center chamber 160 is particularly long and narrow. It is difficult to insert a foam member in such a long narrow chamber. However, the stiffness of the foam after being felted allows the foam member to be more easily inserted in to the center chamber and reduces the likelihood that wrinkles or non-uniformities occur in the foam. It is extremely important to avoid such non-uniformities, because at each position where the foam has localized high compression, the foam at these positions will have a slightly higher capillarity and will cause a certain amount of ink to be stranded at these locations in the foam.

Additionally, this stiffness helps in maintaining a positive compression and seal between ink pipe 168 and foam member 130. Foam members 132 and 134 are much more easily inserted into the side chambers 162 and 164. But even in this orientation the additional stiffness achieved by the felting process helps in keeping the foam bodies 132 and 134 in compressive contact with ink pipes 170 and 172. For the foam in all three chambers, the felting axis or direction is in the same, and is the direction in which the felting presses 210 and 212 move during the felting process, which is the X direction as shown in FIGS. 6 and 7.

As stated, the center chamber 160 is wider near its top than near its bottom, or closer to the bottom wall 174. The center foam member 130 after felting is about the width of the center chamber near its top. Therefore, the center foam member 130 is additionally compressed by inward walls 176 and 178 as the center foam member is inserted into center chamber 160.

Loading of the foam in the center chamber is improved over previous generation pens because of the "near net" size of the foam slabs used in pen 24. The volumes of the ink chamber cavities as compared to the volume of the foam prior to insertion is set forth in the following Table 4.

Table 4

Volume Comparisons (cc's)			
Pen Type	**Cavity**	**Foam**	**Foam/Cavity Ratio**
51606A (PaintJet black)	23.28	35.28	1.51
51606A (PaintJet color)	7.36	10.98	1.49
51608A (DeskJet black)	36.53	67.69	1.85
51625A (DeskJet color)	15.27	23.99	1.57
Center Chamber 160	35.71	45.13	1.26
Side Chambers 162, 164	36.04	44.18	1.23

Thus in the previous generation HP foam-based pens, the foam/cavity volume ratios are on the order of about 1.5 or greater. This means that the overall volume of foam before insertion into the chambers was at least 50% greater than the actual volume of the chamber into which the foam was inserted. This requires that the foam be squeezed into the chambers during the insertion process. This squeezing requires special machinery to insert the foam into the chambers while it is compressed by some means.

Before the development of the present invention, it was believed that this extra pre-insertion volume of foam was necessary to achieve proper compressive contact between the foam, the interior walls of the pen, and the ink pipe. However, because of the increased felting of the foam members in pen 24, which adds significant amounts of stiffness, the foam members can be closer to the cavity volume before insertion into the cavity. As shown in Table 3, the foam members of pen 24 have a pre-insertion volume that is between 1.23 to 1.26 times the cavity volume. The foam members thus have a pre-insertion volume that is about 125% of the cavity volume, which in effect becomes the post-insertion volume. A pre-insertion volume that is less than 130% of its post-insertion volume is preferable, and a pre-insertion volume about 125% is highly preferable. A pre-insertion volume less than 130% of the post-insertion volume is considered to be "near net size."

FIG. 9 is a graph of the negative pressure or backpressure of the fluid presented to the nozzle group from center chamber 160, as a function of the amount of ink that leaves the nozzle group 188. As can be seen, the backpressure increases on a roughly proportional basis and at some point the backpressure begins to increase exponentially.

FIG. 10 is a graph of the backpressure in the ink presented to the nozzle groups 186 and 190 as a function of the volume of ink leaving nozzle groups 186 and 190. As can be seen, the curve of the backpressure in these side chambers has a lower slope than the curve in FIG 9. This lower slope of the curve means that a more even backpressure to the ink presented to the nozzle groups in the side chambers, which enhances the print quality when printing from these side chambers. In addition to providing a more consistent droplet size, the lower slope of the backpressure curve also means that a greater portion of the curve is in the acceptable backpressure range. This means that more ink can be obtained from the foam. It can be seen therefore that the backpressure curve of the center chamber is not as ideal as the outer chambers.

FIG. 11 illustrates a body of reticulated polyurethane foam 234 of uniform pore size but having a cross sectional shape that is trapezoidal. This center foam body can then be inserted into the center chamber, or preferably, felted in the felting direction as shown in FIG. 12 to form a slab of foam having smaller pore sizes near the top. This slab of foam, when inserted into a center chamber, would therefore have a greater capillarity near the top of the chamber and would achieve a backpressure curve with a lower slope. A foam member can also be formed to have a desired capillarity gradient during the fabrication process, for example, during the foaming process. In fact, foam manufacturers typically need to take steps to avoid unintentional capillarity gradients that occur as a natural result of the fabrication process. These naturally occurring capillarity gradients can be controlled to achieve a desired capillarity gradient in a given foam member.

FIG. 13 illustrates how pen 24 is filled. Filling member 240 contains three separate supplies of ink that are attached respectively to three syringes 242, 244, and 246. These syringes are designed to be inserted into the holes 148, 154 and 156 (FIG 4). After filling, plugs 146, 150, and 152 are pressed into the respective holes.

Another embodiment of an ink-jet pen is shown in FIG. 14. This embodiment is only intended to hold a single color or black ink. This pen, generally indicated at 276, could be used as a single pen in a monochrome printer, a black pen in conjunction with a multi-color pen such as pen 24 shown in FIG. 1, or could be part of a four-pen set of one black pen and one pen for each of the primary colors. The illustrated pen includes an ink chamber 278 formed by main body member 280, a cover member 282, and a foam member 284. Main body member 280 is unitarily molded to include an ink pipe 286, and a manifold 288. A stainless steel mesh filter 290 is attached to ink pipe 286. A printhead 292 is attached by means of adhesive to main body member 280, as shown. Cover member 282 is ultrasonically bonded to main body member 280 to enclose foam member 284 within the pen.

The main body member 280 has a trapezoidal cross section, with a decreasing width toward the top of the pen, as shown. Foam member 284 has a rectangular cross section. Foam member 284 is inserted into main body member 280 so that ink pipe 286 and filter 290 locally compresses foam 284 to thereby create a region of localized increased capillarity to attract the ink into the ink pipe 286. Because of the trapezoidal cross section of main body member 280, when inserted into main body member 280, foam member 284 also has an increasing capillarity gradient that increases steadily toward the top of main body member 280. Foam member 284 is the same size and is felted the same amount as foam members 130 and 134. Main body member 280 has the same dimensions as chambers 162 and 164. Therefore, the assembled pen shown in FIG. 14 has a capillary pressure curve that has a desirable lower slope than if the main body member 280 had a uniform-width cross section.

FIG. 15 illustrates another embodiment of a single-color. This pen, generally indicated at 296, includes an ink chamber 298, formed by main body member 300, a foam member 302, cover member 304, ink pipe 306, manifold 308, wire mesh filter 310, and printhead 312. In this embodiment, the main body member 300 has a rectangular cross section, but foam member 302 has a trapezoidal cross section, with its width increasing toward the top. In this embodiment, the capillarity gradient that increases toward the top of the pen is provided by the increased compression due to the larger amount of foam that is compressed into the pen body, which compression increases toward the top of the pen shown.

In the illustrated embodiment of FIG. 15, the foam is uniformly felted to have a uniform width. After felting, the foam is cut to have a trapezoidal cross section. The pen shown in FIG. 15 would have a capillary pressure curve that is more flat than would be provided if foam member 302 had a rectangular cross section. However, the pen in FIG. 14 is preferred to the one shown in FIG. 15 because it is more expensive to provide foam members with non-rectangular cross sections than standard rectangular foam slabs. Relatively speaking it is much less expensive to produce a plastic part, such as main body member 280, that has an irregular cross section.

Claims

1. An ink storage device for an ink-jet printing system, said ink storage device being oriented in said printing system to have a top and a bottom as considered in a gravitational reference frame, the ink storage device comprising:

an ink chamber (160,162,164,278,298);

a porous member (160,132,134,284,302) inserted in said ink chamber, said porous member having a generally increasing capillarity from the bottom of said ink chamber (160,162,164,278,298) toward the top of said ink chamber; and

a body of ink stored in said or porous member (130,132,134,284,302).

2. An ink-jet pen (22,24,276) according to claim 1, further comprising:

a printhead (142,292) fluidically coupled to said ink chamber (162,164,278);

wherein said ink chamber (162,164,278) has a decreasing width extending from its bottom upward along its height.

3. An ink-jet pen (22,24) according to claim 2, the pen (22,24) comprising:

a printhead (142);

a center ink chamber (160) fluidically coupled to said printhead (142);

two side ink chambers (162,164) mounted on either side of said center ink chamber (160) in a scanning direction, each said side ink chamber (162,164) being fluidically coupled to said printhead (142) and having a generally decreasing width from its bottom to its top;

a said porous member (130,132,134) mounted in each of said center (160) and side ink chambers (162,164); and

a body of ink filled into each said porous member (130,132,134).

4. An ink storage device or pen (22,24,276) according to any of claims 1-3 wherein said or each porous member (130,132,134,284) has a generally uniform width before insertion into said or each ink chamber (160,162,164,278).

5. An ink storage device or pen (22,24,276,296) according to any of claims 1-4 further comprising an ink pipe (168,170,172,286,306) extending into compressive contact with said or each porous member (130,132,134,284,302) at a position near the bottom of said or each ink chamber (160,162,164,278,298) to locally compress said or each porous member in the region of said or each ink pipe (168,170,172,286,306), said or each ink pipe being fluidically coupled to said printhead (142,292,312).

6. An ink storage device or pen (22,24,276,296) according to any of claims 1-5 further comprising a filter (136,138,140,290,312) mounted to said or each ink pipe (168,170,172,286,306) and also extending into compressive contact with said or each porous member (130,132,134,284,302).

7. An ink storage device or pen (22,24,276,296) according to any of claims 2-6 wherein said generally decreasing width is measured in said scanning direction.

8. An ink storage device or pen (22,24,276,296) according to any of claims 1-7 wherein said porous member (130,132,134,284,302) is a synthetic foam that is felted in said scanning direction prior to insertion into said or each ink chamber (160,162,164,278,298).

9. A method manufacturing an ink storage device or pen (22,24,276) according to any of claims 2-8, the method comprising:

providing an ink chamber an ink chamber (162,164,278) having a decreasing width extending from its bottom upward along its height;

inserting a foam member (132,134,284) into said ink chamber (162,164,278);

attaching a cover member (112,114,282) to said ink chamber (162,164,278) to enclose said foam member (132,134,284) in said ink chamber (162,164,278); and

filling ink into said or each foam member (132,134,284).

10. A method according to claim 9 further comprising the step of felting said or each foam member (132,134,284) at least about 500% before insertion into said ink chamber (162,164,278).

11. A method of providing an ink storage device or pen (22,24,276,296, the method comprising:

providing an ink chamber (160,162,164,278,298) with an internal foam member (130,132,134,284,302) having a generally increasing capillarity from the bottom of said ink chamber (160,162,164,278,298) toward the top of said ink chamber; and

filling ink into said foam member (130,132,134,284,302).

12. A method according to claim 11, further comprising the steps of:
inserting a needle member (242,244,246) into said or each foam member (130,132,134,284,302); and
injecting ink into said or each foam member (130,132,134,284,302).

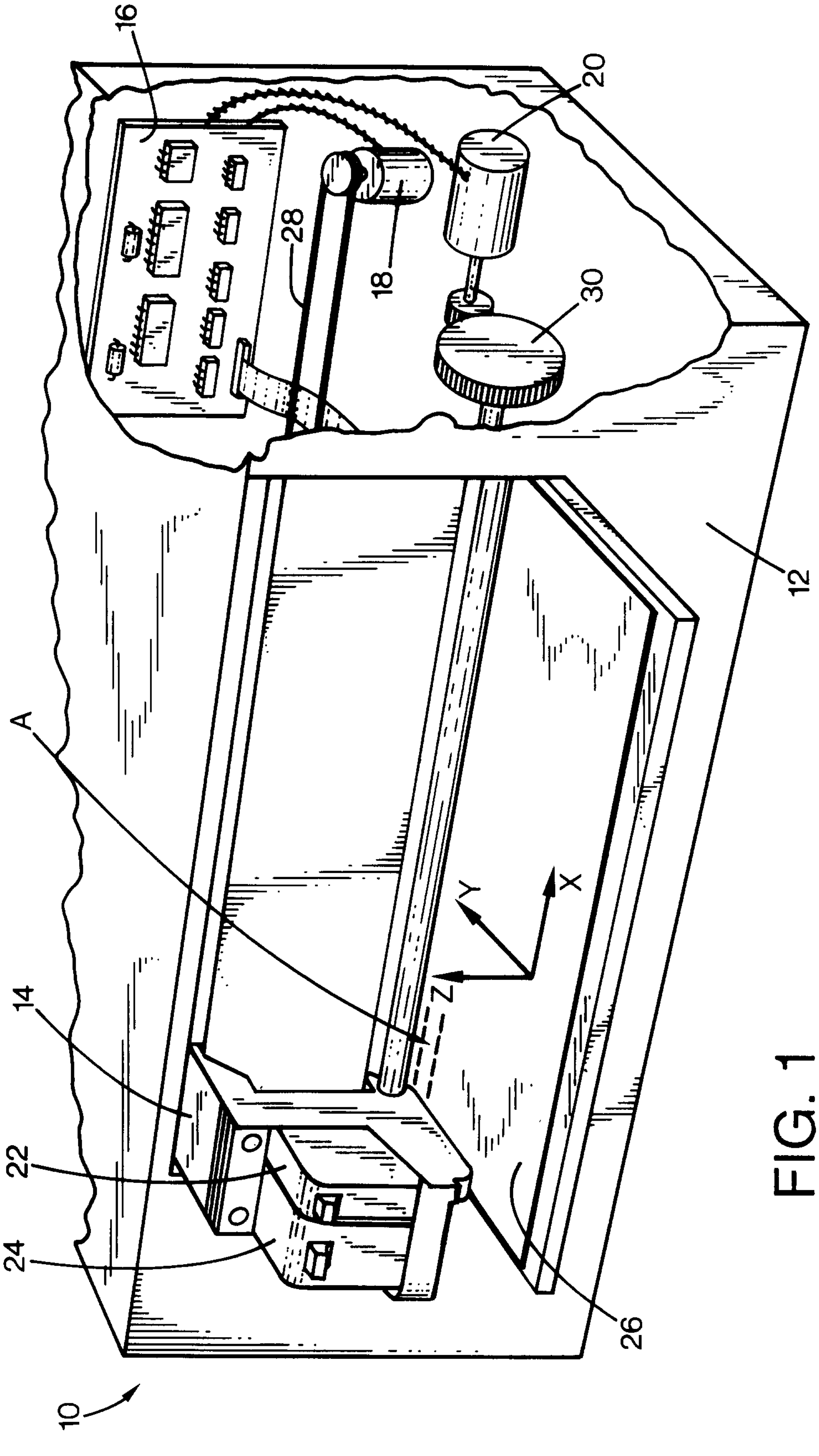
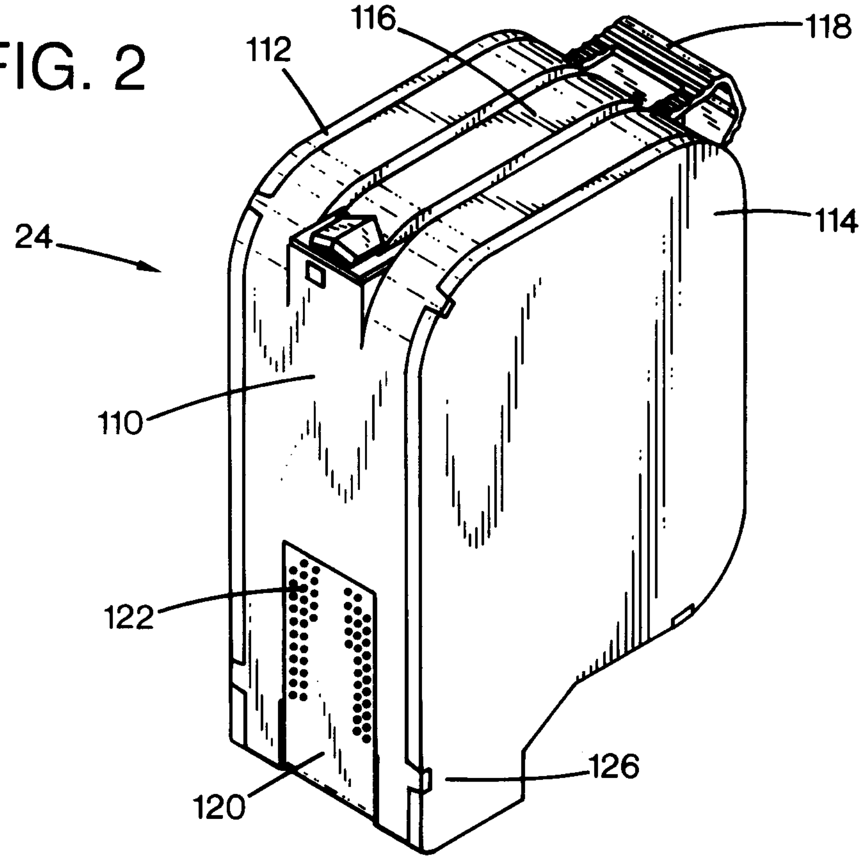


FIG. 1

FIG. 2



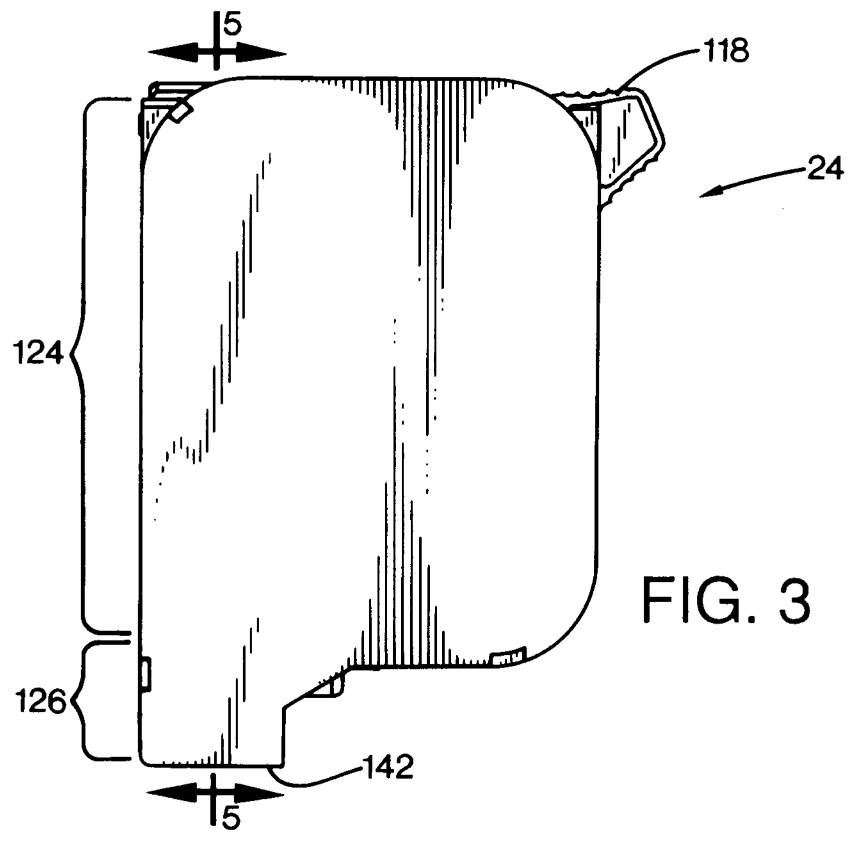
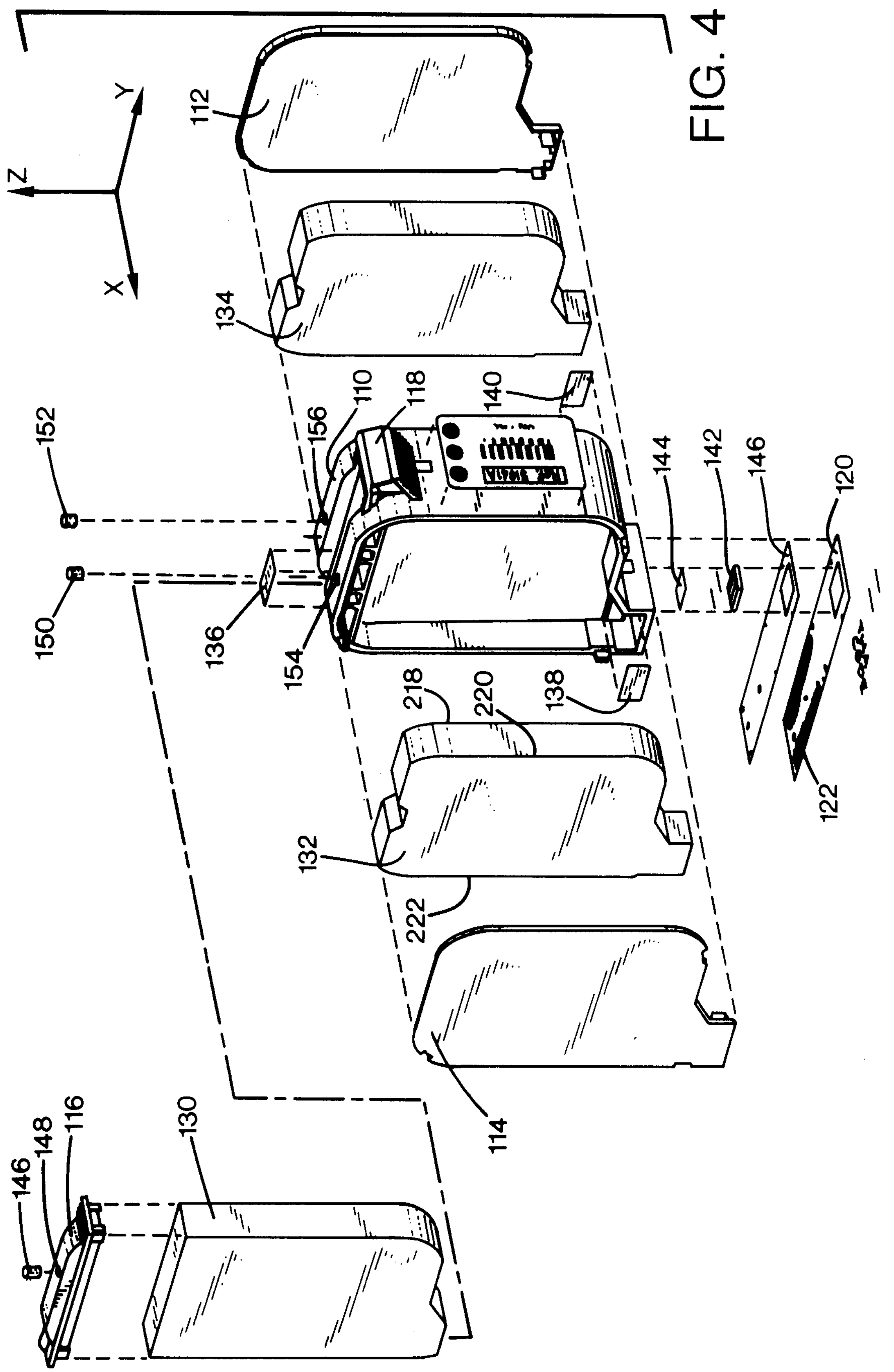


FIG. 3


112
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140
156
152
144
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136
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138
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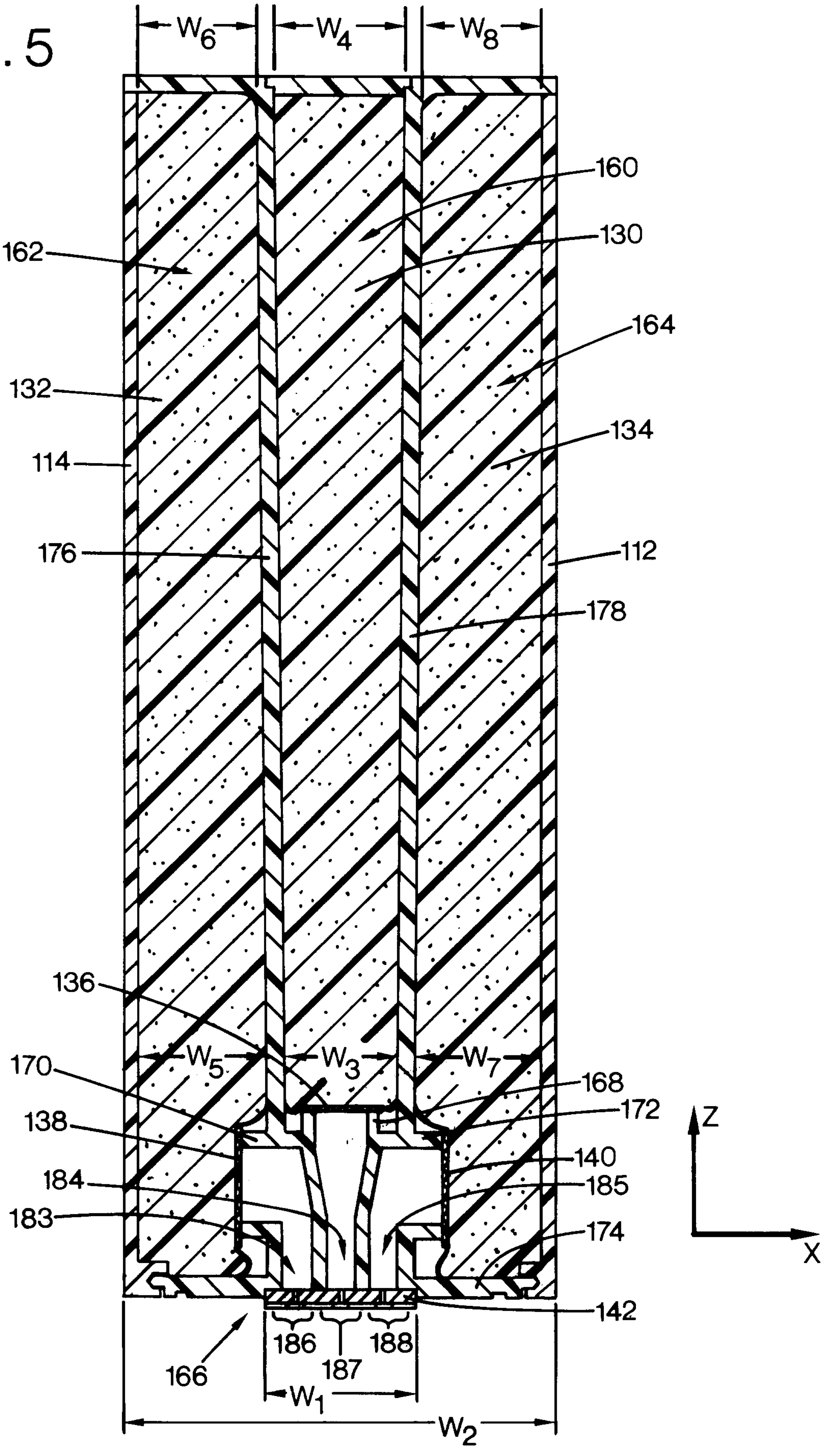
222
122
114
130
116
148
146

FIG. 4

FIG. 5


W6
W4
W8
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130
162
164
132
134
114
112
176
178
136
W5
W3
W7
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172
138
140
184
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183
174
142
186
187
188
166
W1
W2
Z
X

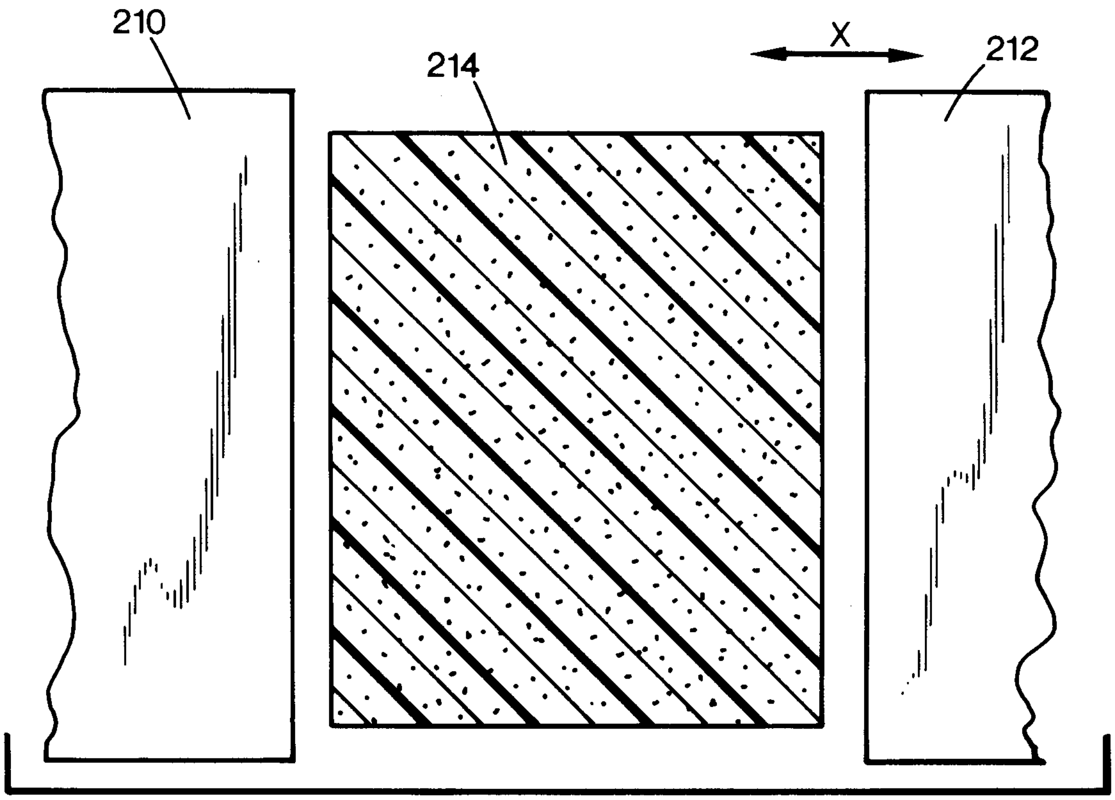
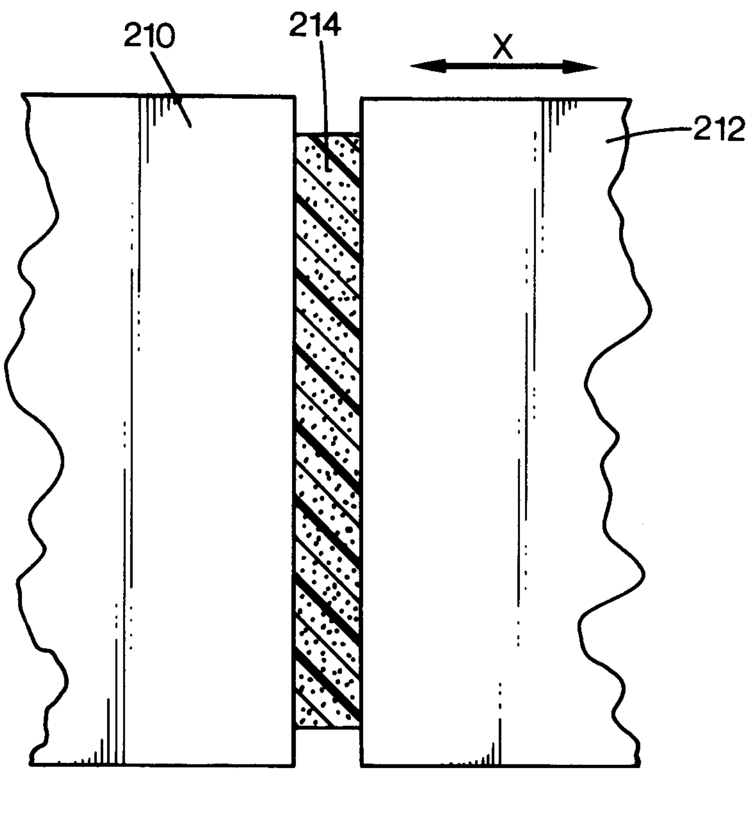


FIG. 6

FIG. 7



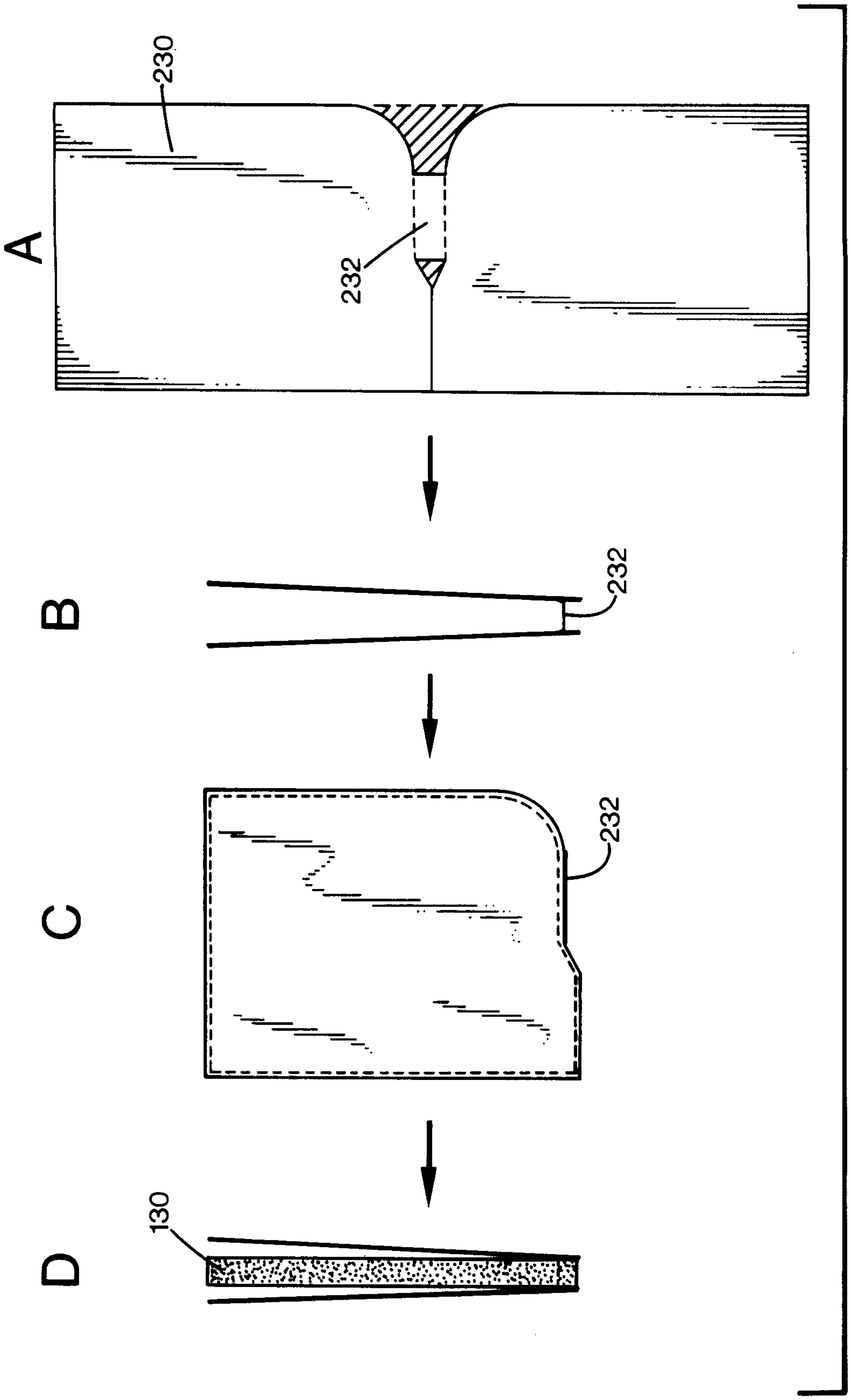


FIG. 8

FIG. 9

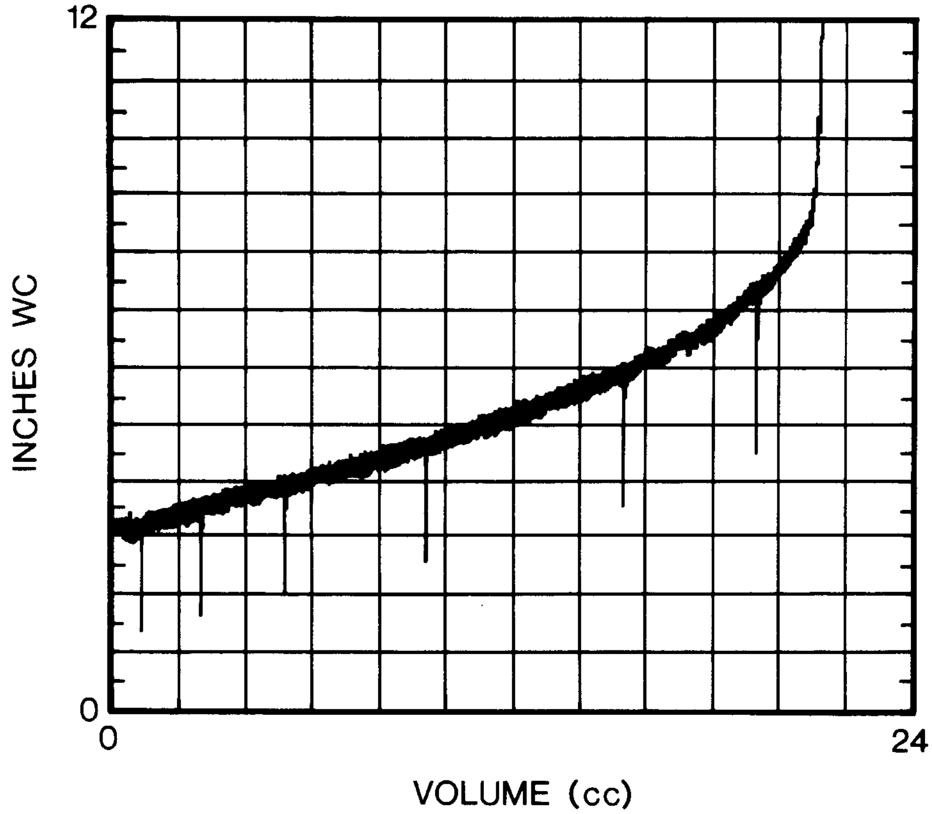


FIG. 10

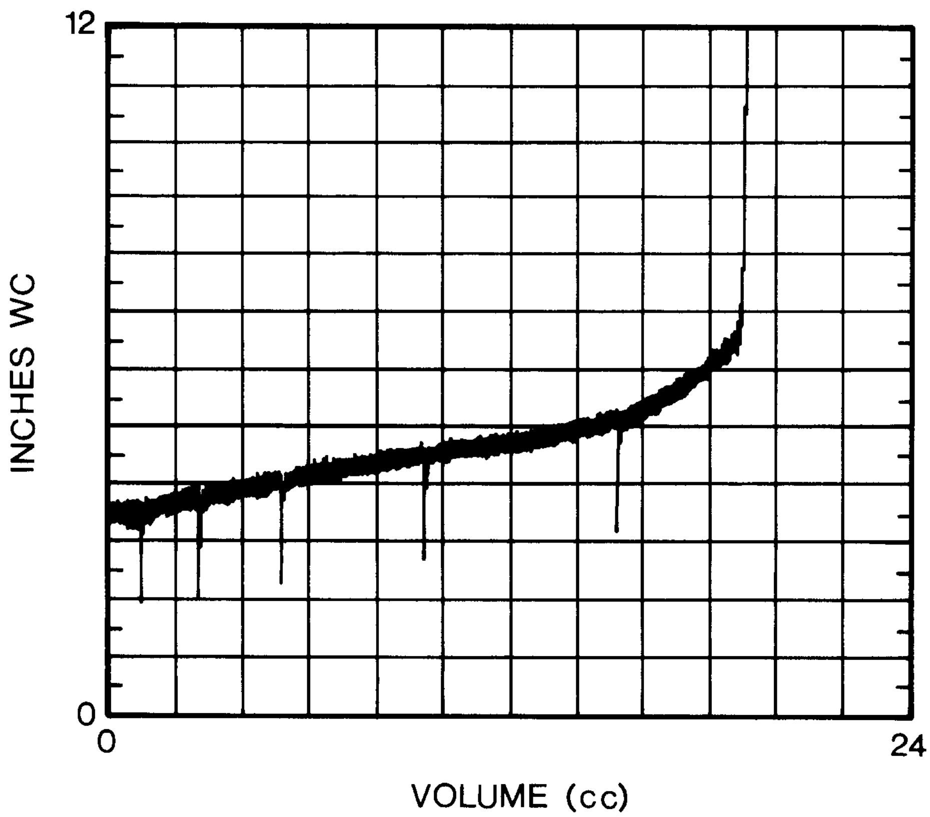


FIG. 11

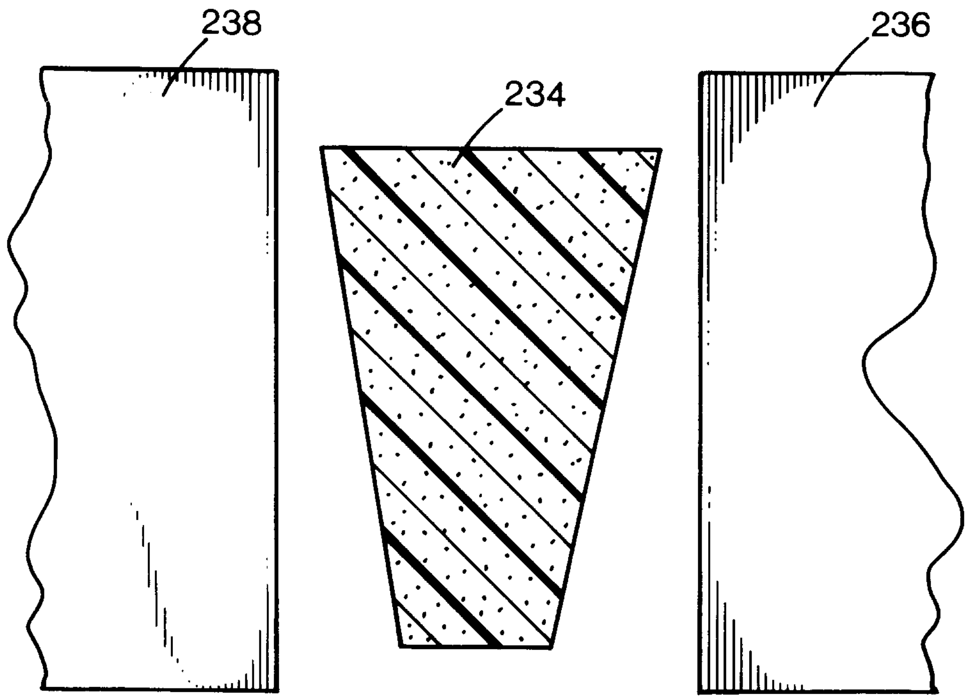


FIG. 12

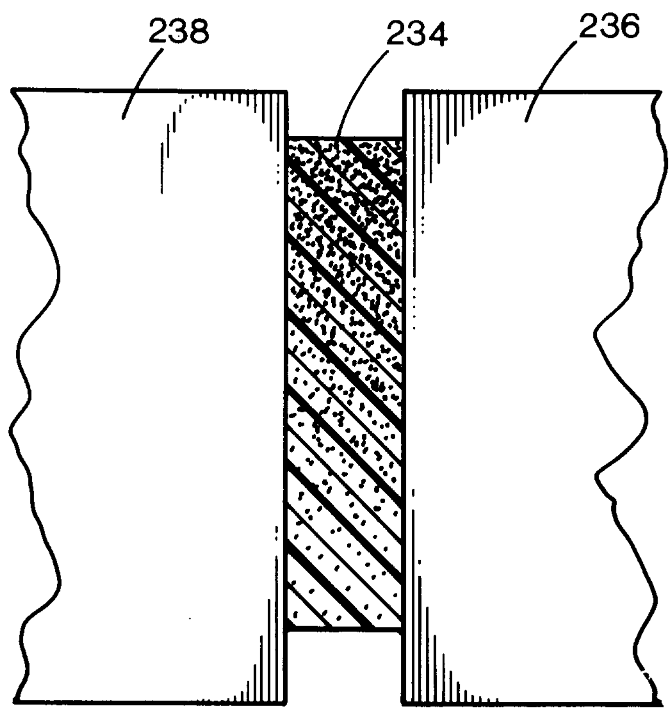
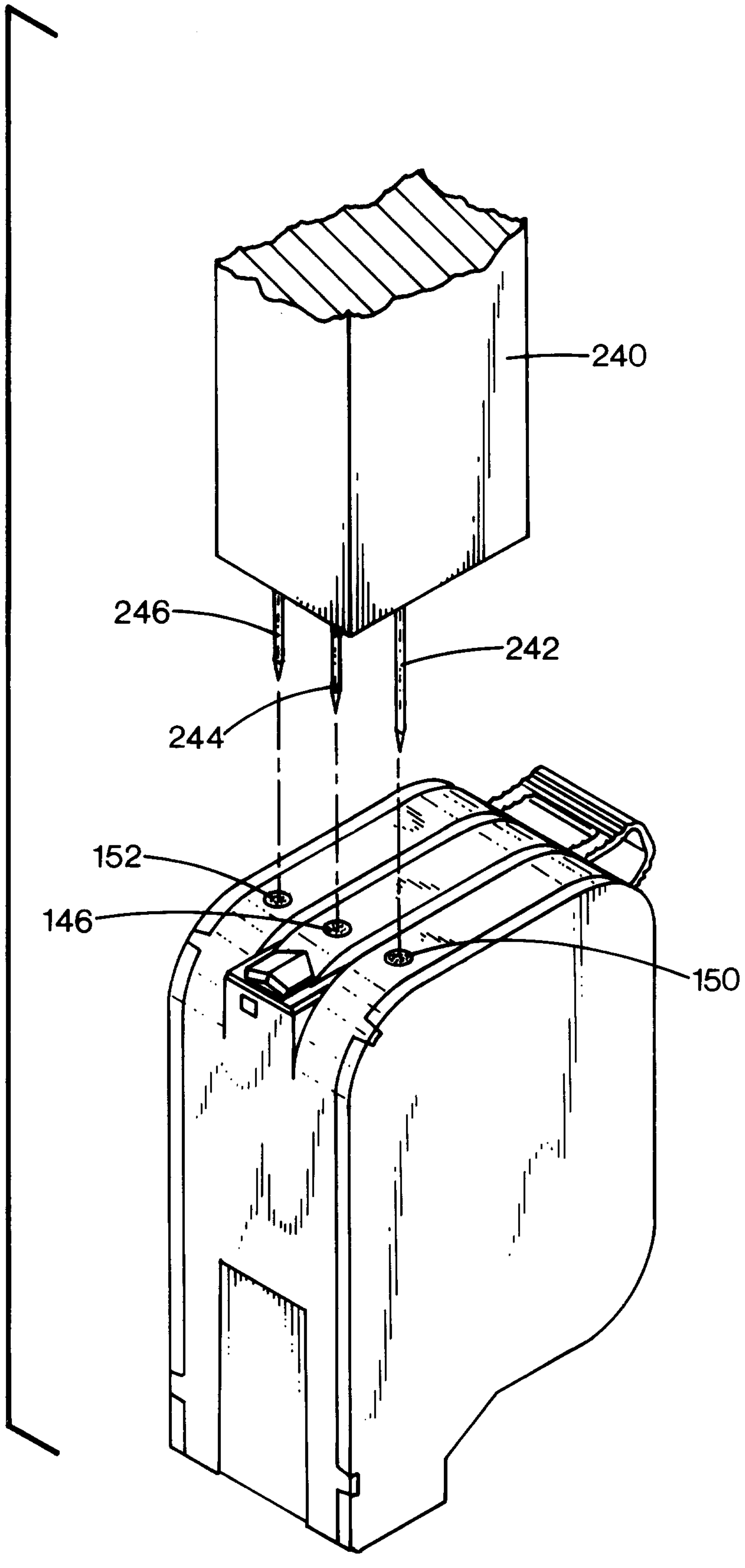


FIG. 13



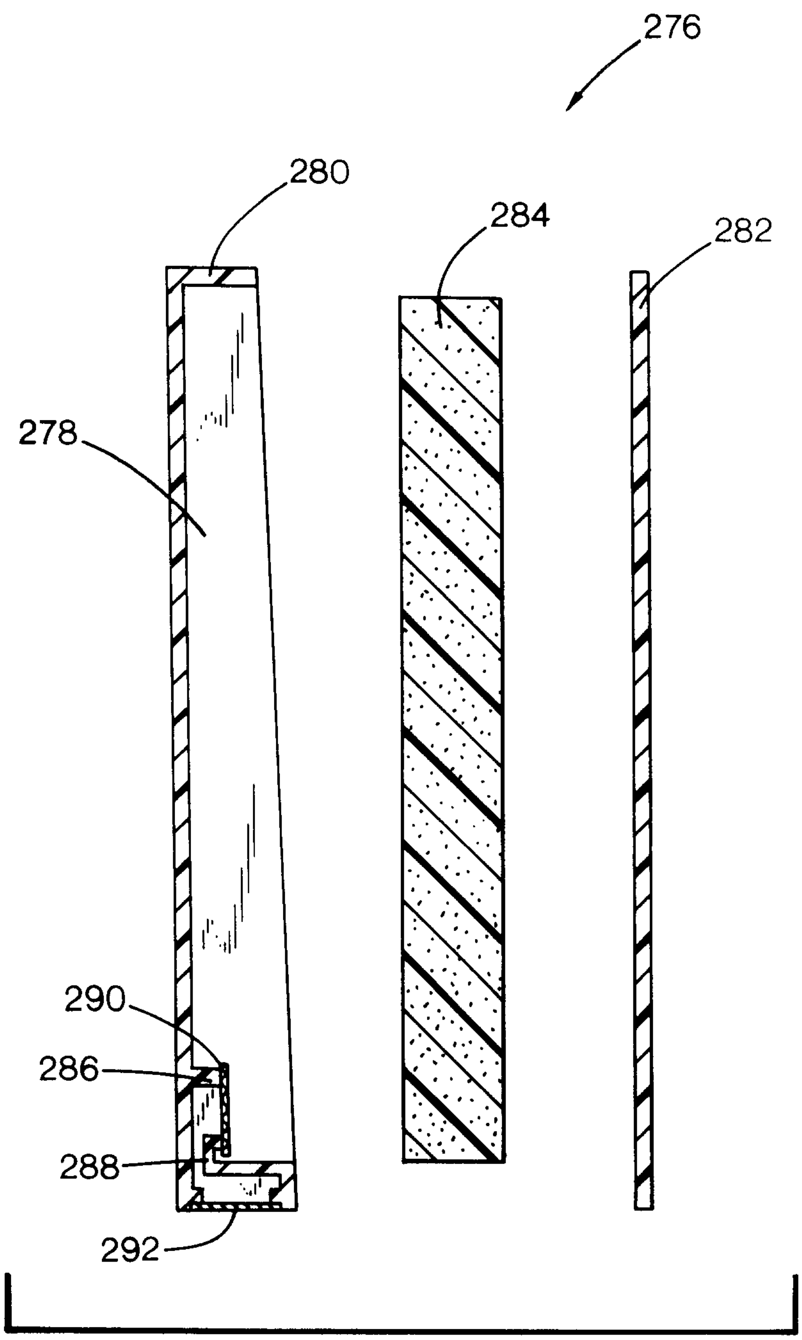


FIG. 14

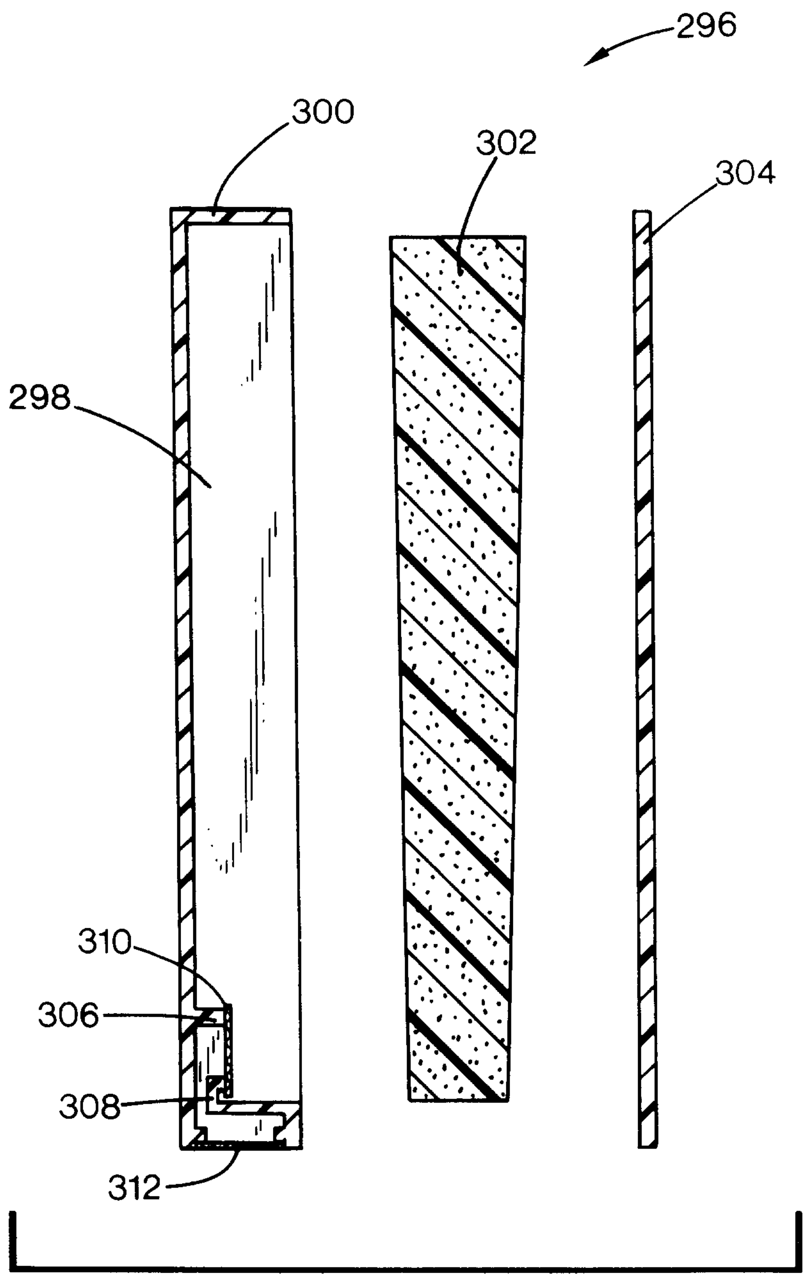


FIG. 15

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 95 30 6684

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X	PATENT ABSTRACTS OF JAPAN vol. 013 no. 083 (M-802) ,27 February 1989 & JP-A-63 281850 (CANON INC) 18 November 1988, * abstract *	1,11	B41J2/175
A	US-A-4 794 409 (COWGER BRUCE ET AL) 27 December 1988 * column 3, line 7 - line 22; figure 1 *	1-12	
A	EP-A-0 424 133 (CANON KK) 24 April 1991 * page 13, line 10 - line 52; figure 21 *	1-12	
A	PATENT ABSTRACTS OF JAPAN vol. 013 no. 067 (M-798) ,15 February 1989 & JP-A-63 268682 (FUJI KAGAKUSHI KOGYO CO LTD) 7 November 1988, * abstract *	1-12	
A	EP-A-0 536 980 (OLIVETTI & CO SPA) 14 April 1993 * column 3, line 19 - line 25; figure 5 *	1-12	TECHNICAL FIELDS SEARCHED (Int.Cl.6)
D,A	US-A-4 771 295 (BAKER JEFFREY P ET AL) 13 September 1988 * the whole document *	1-12	B41J

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	18 December 1995	Joosting, T

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

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