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(54) A head for an ink jet printer.

(57) A head for an ink jet printer comprises an intermediate plate (11) having a plurality of first pressure chambers (12) and first nozzles (13) connected therewith recessed in one surface thereof, a plurality of second pressure chambers (16) and second nozzles (17) connected therewith recessed in the opposite surface thereof. The intermediate plate is disposed between two outer vibration plates (21, 22). Piezo-electric elements (23, 24) are located on the outer vibration plates for ejecting ink from the pressure chambers through the nozzles during a printing operation. A feed channel (15) extends between an ink reservoir (14) and each pressure chamber. It is preferred that the impedance of each feed channel (15) is substantially the same.

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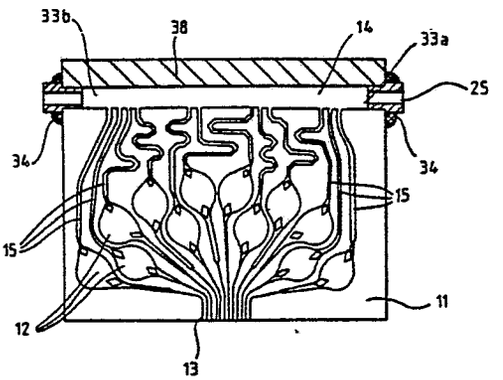

Fig.3.

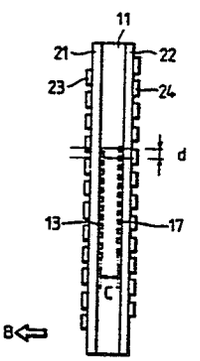

Fig.9

"A HEAD FOR AN INK JET PRINTER"

This invention relates to heads for ink jet printers of the ink-on-demand type.

A conventional ink jet printer of the ink-on-demand type includes a jet having a plurality of nozzles, each connected to a pressure chamber. By changing the capacity of the pressure chambers the ink is ejected from the nozzles to form dots on printing medium. An ink jet printer capable of producing a vertical row of nine dots on the printing medium from which characters can be built up is already commercially available.

An ink jet printer can easily be made to produce selectively numerous type faces or founts. However, in order to obtain a print quality of almost the same standard as the print quality produced by fixed type, it is necessary to arrange the nozzles so that there are 10 per millimetre. However, to arrange the nozzles with such close spacing is difficult even with the aid of precision manufacturing techniques, such as chemical etching.

According to the present invention, there is provided a head for an ink jet printer comprising an intermediate plate having a plurality of first pressure chambers and first nozzles connected therewith recessed in one surface thereof, a plurality of second pressure chambers and second nozzles connected therewith recessed in the opposite surface thereof, the intermediate plate being disposed between two outer plates,

electromechanical transducer means for ejecting ink from said pressure chambers through said nozzles during a printing operation, and a feed channel extending between an ink reservoir means and each pressure chamber characterised in that said transducer means are located on said outer plates and in that said outer plates are vibration plates.

Preferably the impedance of each feed channel is substantially the same.

Preferably each outer plate is common to the plurality of pressure chambers on the respective adjacent surface of the intermediate plate.

The first pressure chambers preferably are offset relative to the second pressure chambers.

An island may be disposed adjacent an inlet of each pressure chamber.

An island may be disposed adjacent an outlet of each pressure chamber.

An island may be disposed in each feed channel.

In one embodiment the feed channels each have substantially the same length.

The outer plates and said intermediate plates may be bonded together.

In one embodiment the ink reservoir means is constituted at least in part by said intermediate plate.

Preferably the head includes a further channel between each pressure chamber and the respective nozzle, the nozzle having a depth in the direction of thickness of the intermediate plate which is less than the corresponding depth of the further feed channel.

The invention is illustrated, merely by way of example, in the accompanying drawings, in which:-

Figure 1 is a front view of one embodiment of a conventional head for an ink jet printer;

Figure 2 is a front view of another embodiment of a conventional head for an ink jet printer.

Figure 3 is a plan view of one embodiment of an intermediate plate of a head according to the present invention for an ink jet printer;

Figure 4 shows part of the intermediate plate of Figure 3 in greater detail.

Figure 5 is a plan view of another embodiment of an intermediate plate of a head according to the present invention for an ink jet printer;

Figure 6 is a plan view of a further embodiment of an intermediate plate of a head according to the present invention for an ink jet printer;

Figure 7 is a plan view of a locating plate of a head according to the present invention for an ink jet printer;

Figure 8 illustrates graphically operation of a head according to the present invention for an ink jet printer;

Figure 9 is a front view of a head according to the present invention for an ink jet printer;

Figure 10 illustrates printing produced by the head of Figure 9;

Figure 11 is a cross-section of a nozzle of a head according to the present invention for an ink jet printer;

Figure 12 shows, schematically, the disposition of a head according to the present invention for an ink jet printer in printing apparatus; and

Figure 13, consisting of Figures 13a, 13b, 13c shows, in perspective, heads according to the present invention for ink jet printers and including the intermediate plates of Figure 3, 5 and 6 respectively.

Referring to Figure 1,there is shown a head of one conventional ink jet printer which is advanced during a printing operation in the direction of an arrow A. The head has a plurality of nozzles 1 through which ink is ejected during a printing operation, the nozzles being spaced apart by distance a. To reduce the vertical spacing of dots formed on a printing medium by ink ejected through the nozzles 1, the head is inclined to direction A, so that the spacing of the dots is b. However, when the conventional head is used in printing apparatus such as a typewriter, for example, while a nozzle 1a is being used to form dots of a first character, a nozzle 1b is being used to form the dots of a second adjacent character. Thus different characters may be printed at the same time and so, as a result, it is necessary to increase the number of character generators or memory circuits, and this complicates control circuitry of the printing apparatus. On the other hand, if characters are printed one-by-one, for example, using input keys of the printing apparatus, the head has to be back-spaced after it has printed one character in order to prepare for printing the next character. Thus the conventional head shown in Figure 1 is somewhat inconvenient and requires relatively complex control circuitry. Moreover, energy consumption, vibration, etc., is increased caused by the need to back-space the head. Furthermore, there are problems associated with the fact that the head occupies a considerable space.

Another conventional head for an ink jet printer is illustrated in Figure 2. This conventional head has a plurality of nozzles 4 each connected to a pressure chamber (not shown). The nozzles 4 are formed on a plate 3. Piezo-electric elements 6 are fixed in positions corresponding to the respective pressure chambers on a vibration plate 5 fixed to the plate 3.

The conventional head of Figure 2 also has a plurality of nozzles 4' each connected to a respective pressure chamber (not shown).

The nozzles 4' are formed in a plate 3'. Piezo-electric elements 6' are fixed in positions corresponding to the respective pressure chambers on a vibration plate 5' fixed to the plate 3' so that the piezo-electric elements 6, 6' are adjacent to one another.

As shown in Figure 2, the nozzles 4 and nozzles 4' are offset by one half pitch in the vertical direction. This conventional head has the advantage that its area can be reduced and made as small as possible. However, the distance between the nozzles 4 and the nozzles 4' is limited by the thickness of the vibration plates 5, 5' and the thickness of the piezo-electric elements 6, 6'. Thus, as with the conventional printer of Figure 1, while one character is being printed by the nozzles 4, another character is printed by the nozzles 4'. Moreover, delicate adjustment is necessary in order to ensure that the nozzles 4 are exactly offset from the nozzles 4' by just one half pitch. This means that the conventional head of Figure 2 is expensive to manufacture.

One embodiment of an intermediate plate of a head according to the present invention for an ink jet printer is illustrated in Figures 3 and 4. The intermediate plate 11 has a plurality of pressure chambers 12, each with a depth of several tens to several hundreds of microns formed on one surface thereof by chemical etching. A nozzle 13 is connected to each pressure chamber 12. The pressure chambers communicate with the preliminary feed chamber 14 via feed channels 15. On the other surface of the intermediate plate, a further plurality of pressure chambers 16 (Figure 4) are formed, the pressure chambers 16 being identical to the pressure chambers 12 but offset relative thereto. Each pressure chamber 16 communicates with a nozzle 17, the nozzles 17 being offset from the nozzles 13 by one half pitch. Ink is supplied to the head by feed pipe 25, the ink being drawn into the pressure chambers 12, 16 by capillary

action as ink is ejected from the nozzles 13, 17.

As shown in Figure 9, the intermediate plate 11 is sandwiched between two outer vibration plates 21, 22 to which respective piezo-electric elements 23, 24 are fixed.

The operation of the head shown in Figures 3, 4 and 9 will now be described. During a printing operation, the head is moved in the direction of an arrow B (Figure 9) by a mechanism (not illustrated) of a printing apparatus and the piezo-electric elements 23, 24 are energised by control signals from control circuitry (not shown). The capacity of the pressure chambers 12, 16 suddenly changes corresponding to the control signals applied to the respective piezo-electric elements and ink is ejected from the nozzles on to a printing medium to form dots of the desired character. The distance between the nozzles 13, 17 is indicated by c. The distance c is the determining factor in deciding whether timing of printing of the dots should be made with a built-in delay or the head should be made to move by the distance c from the start. If the distance c is less than a distance e between adjacent characters (Figure 10) the head is not required to print two adjacent characters at the same time and so the control circuitry of the printing apparatus in which the head is incorporated is relatively simple compared with control circuitry for printing apparatus in which the conventional heads of Figures 1 and 2 are incorporated.

The volume and speed of ejection of ink from the nozzles 13, 17 is dependent, inter alia, upon the cross-sectional area of the respective pressure chambers 12, 16 and the length of the feed channels 15. In order to obtain a high quality printing, it is necessary to ensure that the control signals have a constant voltage, constant current and constant phase so that the volume and speed of ejection of ink remains constant. This can be achieved by arranging the length of each of the feed

channels 15 connecting the pressure chambers 12, 16 to the preliminary feed chamber 14 to be the same and/or providing a high impedance element 31 where each feed channel 15 communicates with the respective pressure chamber 12, 16. The distances between the nozzles 13, 17 and the respective pressure chambers 12, 16 may be made the same for the same purpose but this is difficult to achieve in view of the fact that the nozzles are so closely spaced. As shown in Figure 2, if the pressure chambers 12, 16 are offset, a high density of printing can be realised. In Figure 3, the length of each of the feed channels 15 is constant to make their impedance the same. However, it is also possible to make the impedance of the feed channels the same, even if they have different lengths, by suitably arranging the width and/or depth of the feed channels.

Figure 8 shows the relationship between driving voltage and volume of ink ejected where the distance between the pressure chambers 12, 16 and the respective nozzles 13, 17 is constant and the length of the feed channel 15 is changed. In Figure 8, the length of the feed channel 15 in line A is 8 millimetres and in line B is 2 millimetres. Generally, the higher the impedance of the feed channel 15, the greater the volume of ink ejected by the nozzles 13, 17. After ink is ejected and during restoration ready for ink to be ejected again, some air enters the nozzles 13, 17, the amount being dependent, inter alia, upon the surface tension of the ink. However, the ink is subject to different pressures during ejection and during restoration, and the quantity of ink ejected from each nozzle and the time for restoration is made constant for all the nozzles by dimensioning the feed channels 15 suitably to take account of the viscosity of the ink and the impedance of the feed channels.

Ink is more easily ejected from the nozzles when the pressure chambers 12, 16 are smoothly connected to the nozzles 13, 17 respectively and the impedance is low. Thus it is better to increase the width of the feed channels to equalise the impedance of the feed channels. Further, as the piezo-electric elements 23, 24 are circular, it is desirable to make the pressure chambers 12, 16 substantially circular.

Another embodiment of an intermediate plate 11 for a head according to the present invention of an ink jet printer is shown in Figure 6 and has a first island 36 and a second island 35. Unless the pressure chamber 12 is substantially circular, high frequency vibration is generated and the pressure within the chamber 12 does not increase uniformly when a control signal is applied to the respective piezo-electric element. As a result, the ejected ink separates into droplets so that the quality of printing deteriorates. However, the first island 36 and the second island 35 prevent the generation of these high frequency vibrations even if the shape of the pressure chambers deviates from circular. It is thus possible to eject the same volume of ink from each of the nozzles. When the width of feed channels 15 is relatively broad, an island 37 is disposed within each feed channel in order to increase the impedance thereof and again to prevent high frequency vibrations.

In a head for an ink jet printer, it is an essential requirement that no air bubbles occur in the feed channels, pressure chambers, etc., in order to obtain good quality printing. However, there is a considerable risk of generating such air bubbles, for example, air dissolved in the ink may form an air bubble, an air bubble may flow from the preliminary ink chamber, air may enter through the nozzles and form an air bubble, etc. If an air bubble appears within the head the easiest way to remove it is to allow it to escape through the

nozzles. To this end, ink is ejected through the nozzles by applying pressure from the preliminary feed chamber 14, but since the width of the pressure chambers 12, 16 is several times that of the feed channels 15 and the other channels, only air bubbles in the neighbourhood of the centre of the pressure chambers 12 will be ejected through the nozzles 13 and air bubbles adjacent the circumference of the pressure chambers will remain. To overcome this, the second islands 35 are provided to ensure that all the air bubbles in the pressure chambers will be ejected through the nozzles.

If the depth of the feed channels 15 is made constant by an etching technique, ejection of ink is somewhat inferior as shown by line C in Figure 8. Further, the time for restoration after ejection of ink becomes relatively long. In order to overcome this, as shown in Figure 11, the depth D_2 of the nozzle 13 (and the nozzle 17) is made less than the depth D_1 of a channel 45 connecting a nozzle to respective pressure chambers. Thus efficiency of ejection of ink and response frequency can be improved. In one embodiment of the present invention, the depth D_2 of each nozzle is 40-50 μm, the length L is 50-300 μm and the depth D_1 of the channel 45 is 70-150 μm in order to achieve the response frequency of about 2 KHz. The required length L of the nozzles has a close relationship with the quantity of air entering the nozzle when ink has been ejected and during restoration. The amount of air entering through the nozzle is exactly the same as the amount of ink that has just been ejected and it is necessary to prevent boundaries between the air and the ink reaching the channel 45. If this occurs, because some ink still adheres to the opposite side walls of the nozzle, the pressure balance may be changed, even though only slightly, and the ink on one side wall of the nozzle may coalesce with the ink on the opposite

side wall and so form an air bubble in the channel 45.

The thickness of the intermediate plate 11 has been found to be very important in practice. If the total thickness of the outer vibration plate 21 and the piezo-electric element 23 is equal to the thickness of the intermediate plate 11, which itself is relatively thin since it is made by an etching technique, pressure will increase by only a half. Further, pressure in one pressure chamber will be transmitted to an adjacent pressure chamber on the opposite side of the intermediate plate. As a result, the volume and speed of ejection of ink will vary depending upon whether the adjacent pressure chambers on opposite sides of the intermediate plate are driven at the same time or not. As a result, the quality of printing is reduced. Therefore, it is necessary to prevent adjacent pressure chambers on opposite sides of the intermediate plate influencing each other or to make the influence so small that it may be disregarded. As the influence between adjacent pressure chambers on opposite sides of the intermediate plate is inversely proportional to the square of the thickness of the intermediate plate, in order to control this influence the latter should be preferably about 3.2 times the combined thickness of the outer vibration plate 21 and the piezo-electric elements 23 (or the outer vibration plate 22 and the piezo-electric elements 24). If the outer vibration plate 21 is 0.15 millimetres in thickness and the piezo-electric elements 23, 24 are 0.15 millimetres in thickness, the thickness of the intermediate plate should be 0.95 millimetres. However, since the pressure chambers on one side of the intermediate plate are offset relative to those on the opposite side, as shown in Figure 4, the thickness of the intermediate plate may be reduced to some extent. If the pressure chambers are etched to a depth of, for example, 70 μm, the thickness of the intermediate plate

is given by:

$$0.95 - (0.15 + 0.15 + 0.07) = 0.58 \text{ millimetres.}$$

By disposing the pressure chambers offset with respect to each other, the influence between adjacent pressure chambers on opposite sides of the intermediate plate can be reduced to 0.6 per cent and this can be ignored. Further, as the intermediate plate can be made relatively thin, the distance c between adjacent nozzles is reduced so that the space e between adjacent characters, when a printing operation is performed, as shown in Figure 10, can be reduced.

One method of manufacturing the printing head of Figure 9 will now be described. First, chrome and gold layers are deposited on to a plate made of a material which is not affected by ink, for example, borosilicate glass. A resist is formed on both sides of the plate and is exposed to light using a photo mask so as to form the pattern, for example, in Figure 3. After that, the plate is etched by, for example, hydrofluoric acid to form the channels in the pressure chambers. The gold and chrome layers are removed, a spacer 38 having almost the same thickness as that of the intermediate plate is disposed at one side of where the preliminary feed chamber 14 is to be formed, and then the intermediate plate so formed is sandwiched between the outer vibration plates 21,22 held by a jig, and put into a furnace at 550° to 700°C. Thus the intermediate plate, the spacer 38 and the vibration plates are bonded together. An electrically conducted film, for example, of NESA (Trade Mark) or In_2O_3 is formed on the outer vibration plates 21,22 to act as a transparent electrode. The conductive film may be formed before or after bonding of the intermediate plate and the vibration plates. Further, it is possible to form gold or chrome layers only where required for electrodes of the piezo-electric elements by means of pattern deposition or etching. Since the intermediate plate and the outer vibration plates are transparent, the channels

and pressure chambers are visible but if this is not required, the outer vibration plates and intermediate plates may be made opaque.

Figure 13a shows the intermediate plate 11 and the spacer 38 of Figure 3 disposed between the two outer vibration plates 21, 22 to form a space which defines the preliminary feed chamber 14. The preliminary feed chamber 14 has an ink inlet 33a and an ink outlet 33b. A feed pipe 25 of stainless steel is secured by binder material 34 to each of the ink inlet 33a and the ink outlet 33b.

Figure 13b shows a head for an ink jet printer incorporating the intermediate plate of Figure 5 showing an ink reservoir 39 made, for example, of plastics material.

Figure 13c shows a head for an ink jet printer incorporating the intermediate plate of Figure 6, the preliminary feed chamber 14 being formed by etching on the intermediate plate with the pressure chambers 12.

The ink outlet 33b for the preliminary feed chamber 14 is not essential but when an air bubble, for example, enters the preliminary feed chamber, if ink is circulated therethrough the air bubble can be removed without having to push it through the pressure chambers and nozzles etc.

The shape of the nozzle shown in Figure 11 can be produced by a double etching technique.

After the intermediate plates and outer vibration plates have been bonded, a locating plate 40 (Figure 7) for determining the position of the piezo-electric elements, is fixed in position by a bonding tag 42 and correctly located by a cross-shaped recess 47 engaging correspondingly shaped projections on the respective outer vibration plates. The plate 40 has twelve holes 41 each somewhat larger than the piezo-electric element to be located therein and with a depth of the same as that of

the piezo-electric element to be located therein. If the plate 40 is made of metal, it can be used to form electrodes of the piezo-electric elements. A piezo-electric element is put into each of the holes 41 and fixed therein by means, of, for example an epoxy resin or a metal solder, such as a gold-tin solder. Then each piezo-electric element is wired to control circuitry of the printing apparatus. In order to improve insulation properties, the wiring is sealed by a soft electrically non-conductive material, such as silicon resin. In order to increase resistance to damage due, for example, to external shock, a coating may be formed on the plate 40. The piezo-electric elements may be wired by various methods, such as soldering, electric bonding, wire bonding, or connecting using electric gum, metal etc. Thus a highly integrated head for an ink jet printer can be made. Moreover the surface on which the nozzles debouch may be cut by a diamond cutter or polished to make it smooth.

The wall between one feed channel and the adjacent feed channel preferably has a width of more than 50 μm since it is necessary for the wall to have sufficient strength not to be broken if the ink freezes. It has been found that if the wall between adjacent feed channels has a width of 100 μm, it does not break even when the ink is frozen at $-40^{\circ}C$. As mentioned above, borosilicate glass is preferably used for the intermediate plate and the outer vibration plates due to the ease of etching. However, instead of being etched, the borosilicate glass could be moulded into the desired configuration at high temperature.

A head according to the present invention of ink jet printer may be disposed as shown in Figure 12 and inclined at an angle of θ° to the plane of printing so that a distance $\underline{f}$ between adjacent dots formed on printing medium is less than the distance $\underline{d}$ between corresponding adjacent nozzles, i.e.:

$$f = \frac{d\sin\theta}{2} \leqq \frac{d}{2}$$

As a result high density printing will be obtained.

A head according to the present invention for an ink jet printer may be employed by typewriters, copying presses or facsimile machines etc.

CLAIMS

1. A head for an ink jet printer comprising an intermediate plate (11) having a plurality of first pressure chambers (12) and first nozzles (13) connected therewith recessed in one surface thereof, a plurality of second pressure chambers (16) and second nozzles (17) connected therewith recessed in the opposite surface thereof, the intermediate plate being disposed between two outer plates, (21,22) electromechanical transducer means (23,24) for ejecting ink from said pressure chambers through said nozzles during a printing operation, and a feed channel (15) extending between an ink reservoir means (14) and each pressure chamber characterised in that said transducer means (23,24) are located on said outer plates (21,22) and in that said outer plates are vibration plates.

2. A head as claimed in claim 1 characterised in that the impedance of each feed channel (15) is substantially the same.

3. A head as claimed in claim 1 or 2 in which each outer plate (21,22) is common to the plurality of pressure chambers on the respective adjacent surface of the intermediate plate.

4. A head as claimed in any preceding claim characterised in that the first pressure chambers (12) are offset relative to the second pressure chambers (16).

5. A head as claimed in any preceding claim characterised in that an island (35) is disposed adjacent an inlet of each pressure chamber.

6. A head as claimed in any preceding claim characterised in that an island (36) is disposed adjacent an outlet of each pressure chamber.

7. A head as claimed in any preceding claim characterised in that an island (37) is disposed in each feed channel.

8. A head as claimed in any preceding claim characterised in that the feed channels (15) each have substantially the same length.

9. A head as claimed in any preceding claim characterised in that the outer plates (21,22) and said intermediate plates (11) are bonded together.

10. A head as claimed in any preceding claim characterised in that the ink reservoir means (14) is constituted at least in part by said intermediate plate.

11. A head as claimed in any preceding claim characterised by including a further channel (45) between the pressure chamber and the respective nozzle, the nozzle having a depth in the direction of thickness of the intermediate plate, which is less than the corresponding depth of the further feed channel.

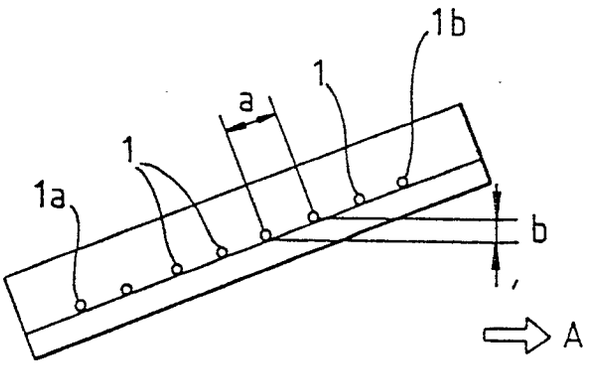

Fig .1.

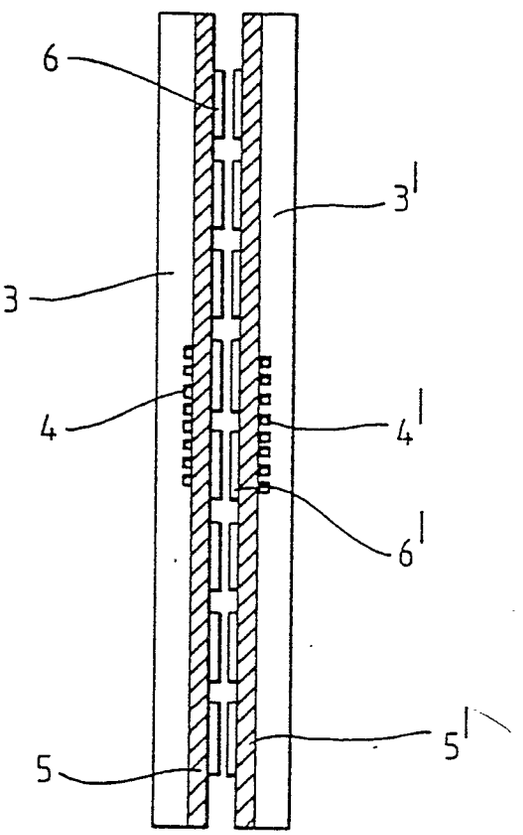

Fig .2.

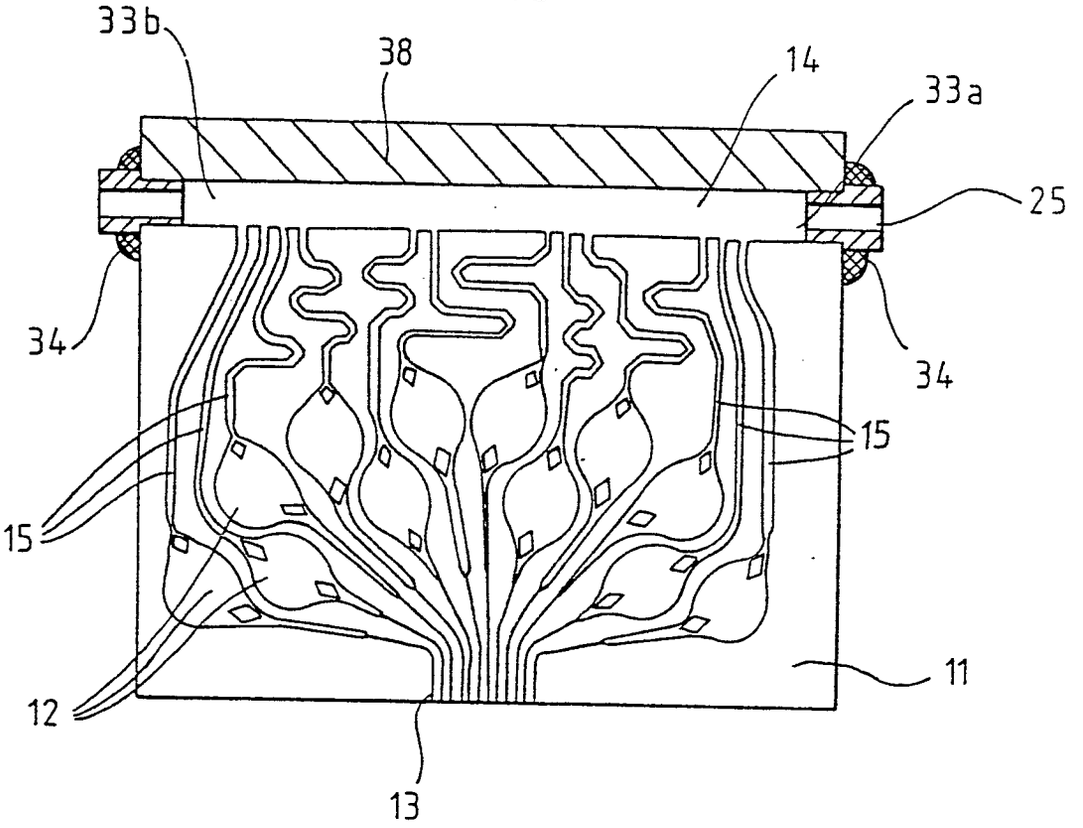

Fig. 3.

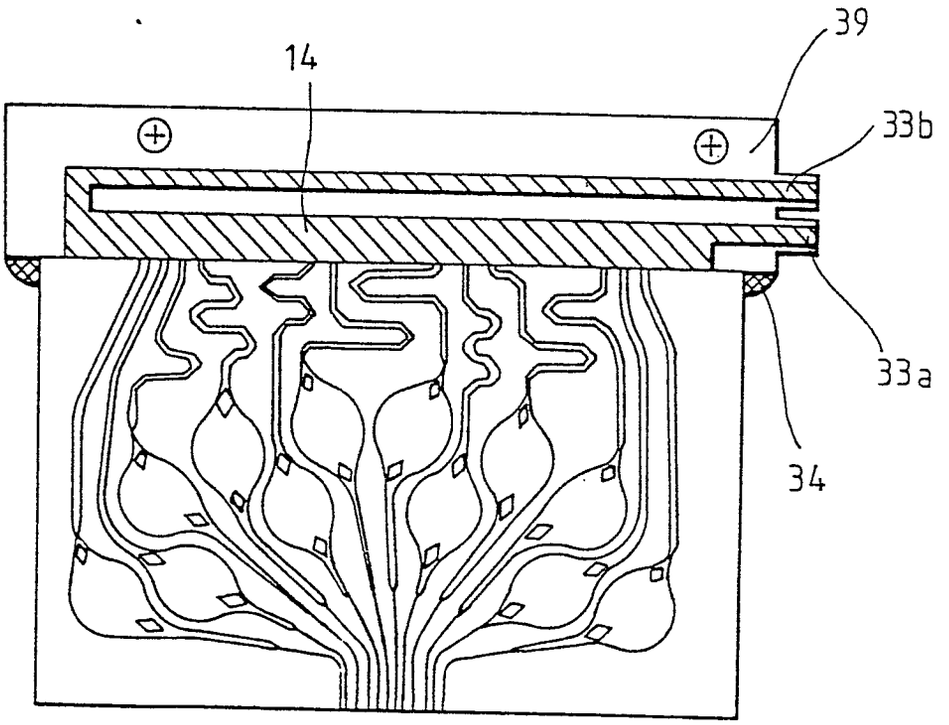

Fig. 5.

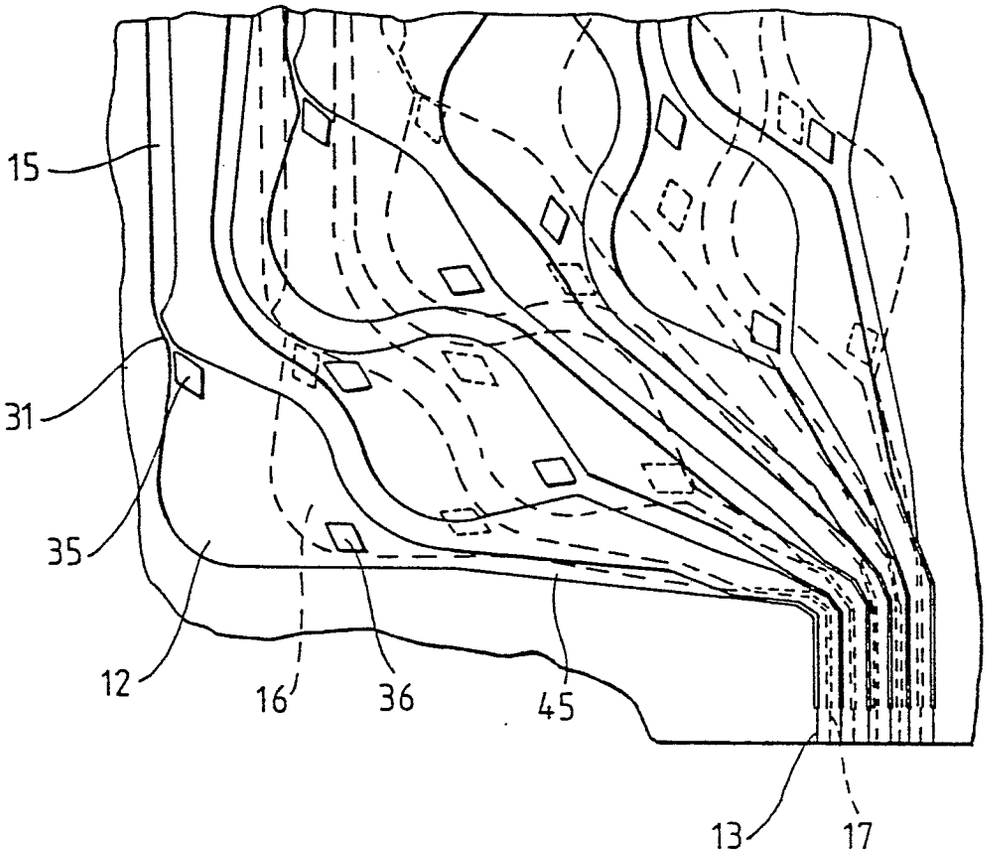

Fig .4.

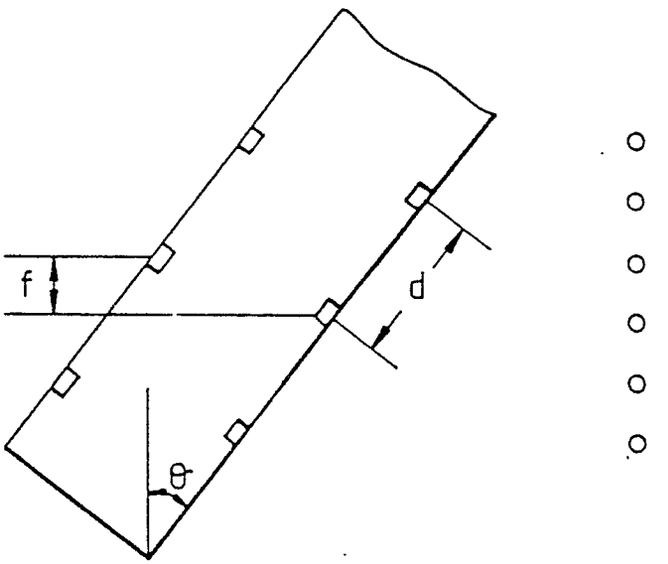

Fig .12.

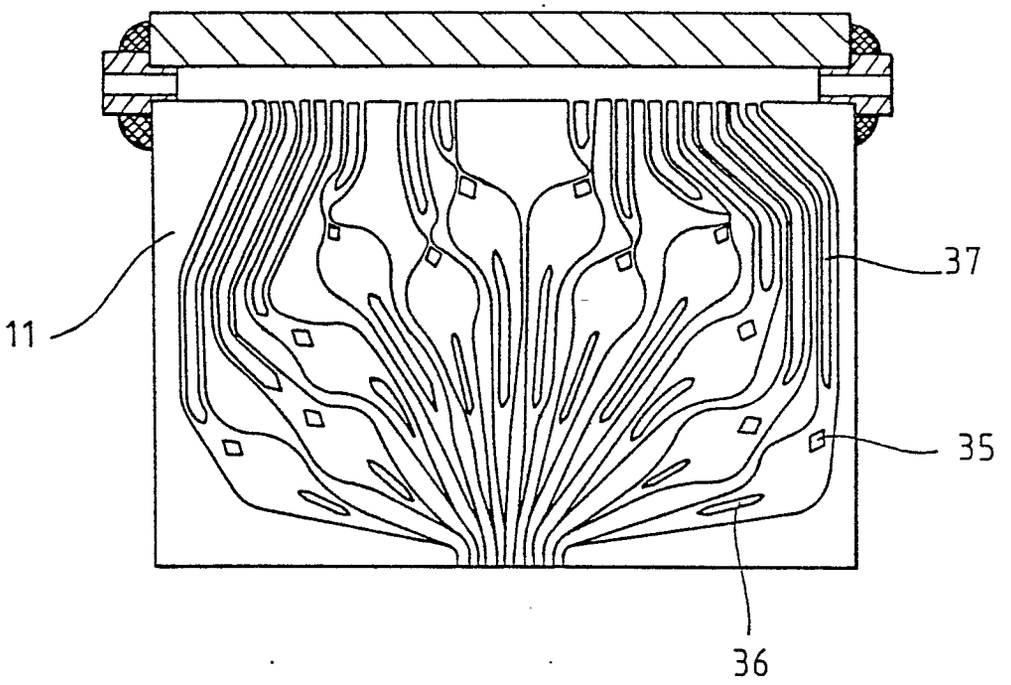

Fig.6.

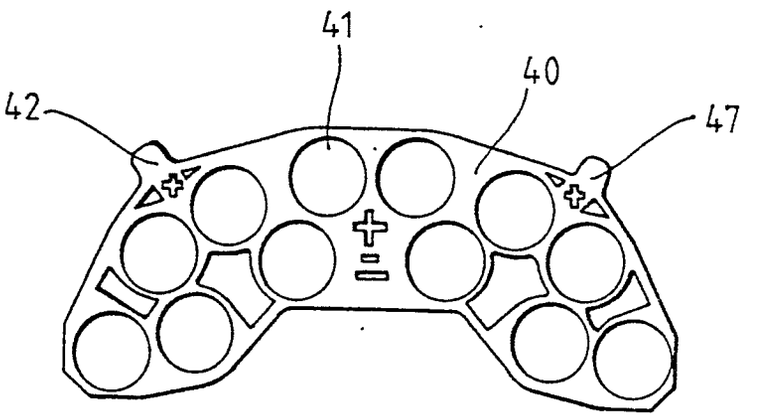

Fig.7.

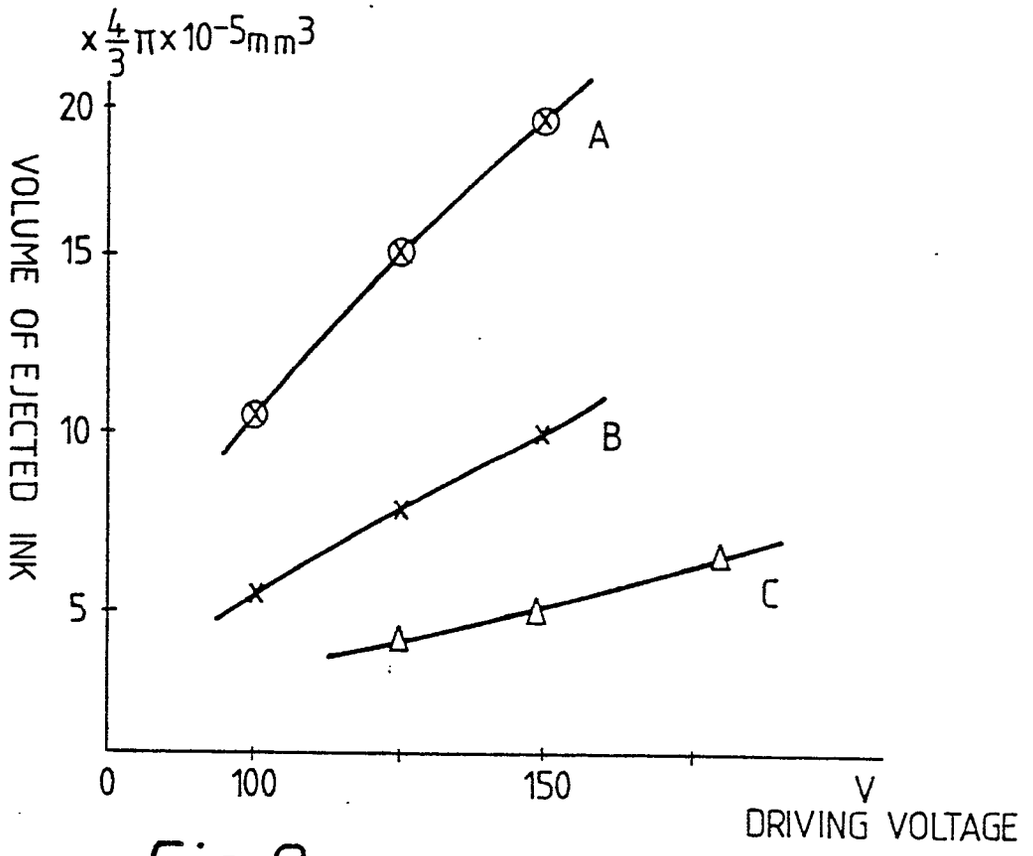
x 4/3 π x 10⁻⁵ mm³
VOLUME OF EJECTED INK
20
15
10
5
0
100
150
V
DRIVING VOLTAGE
A
B
C

Fig.8

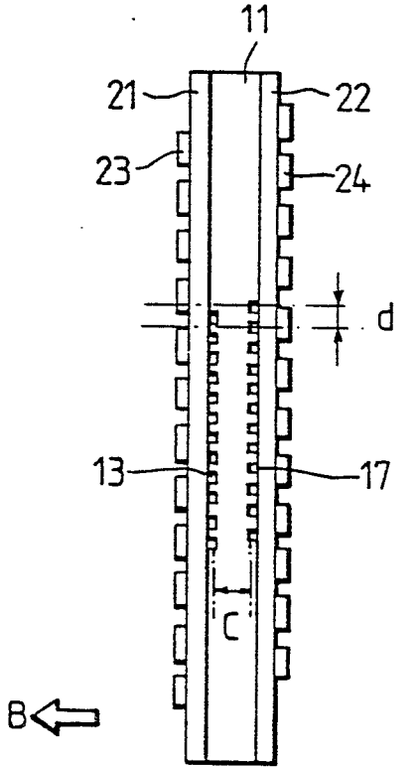
11
21
22
23
24
d
13
17
C
B

Fig.9

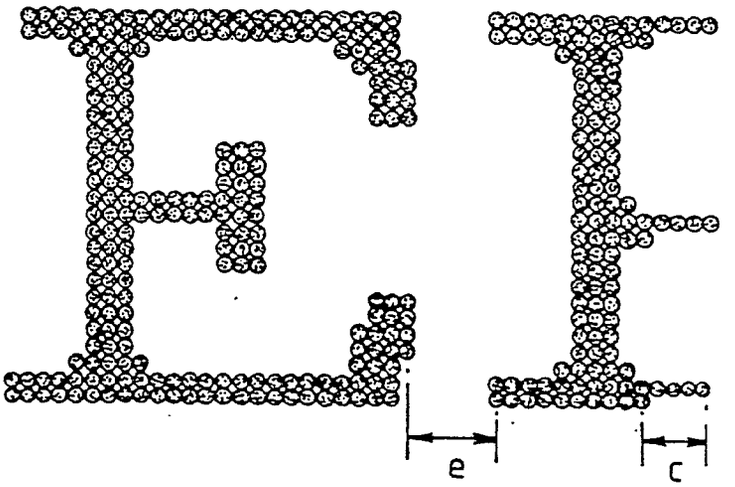

Fig. 10

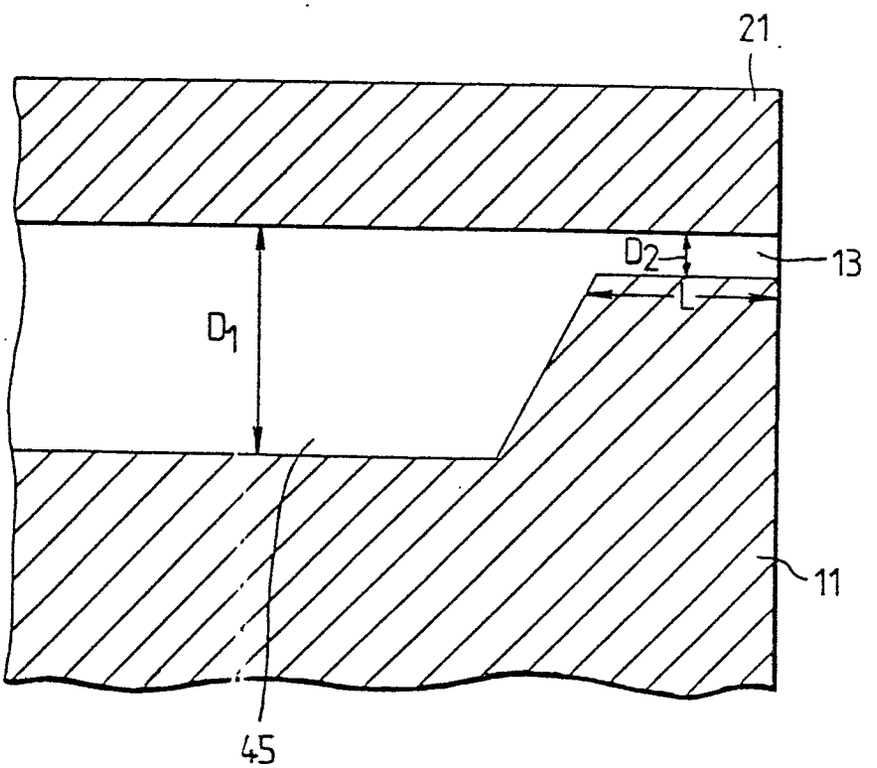

Fig. 11

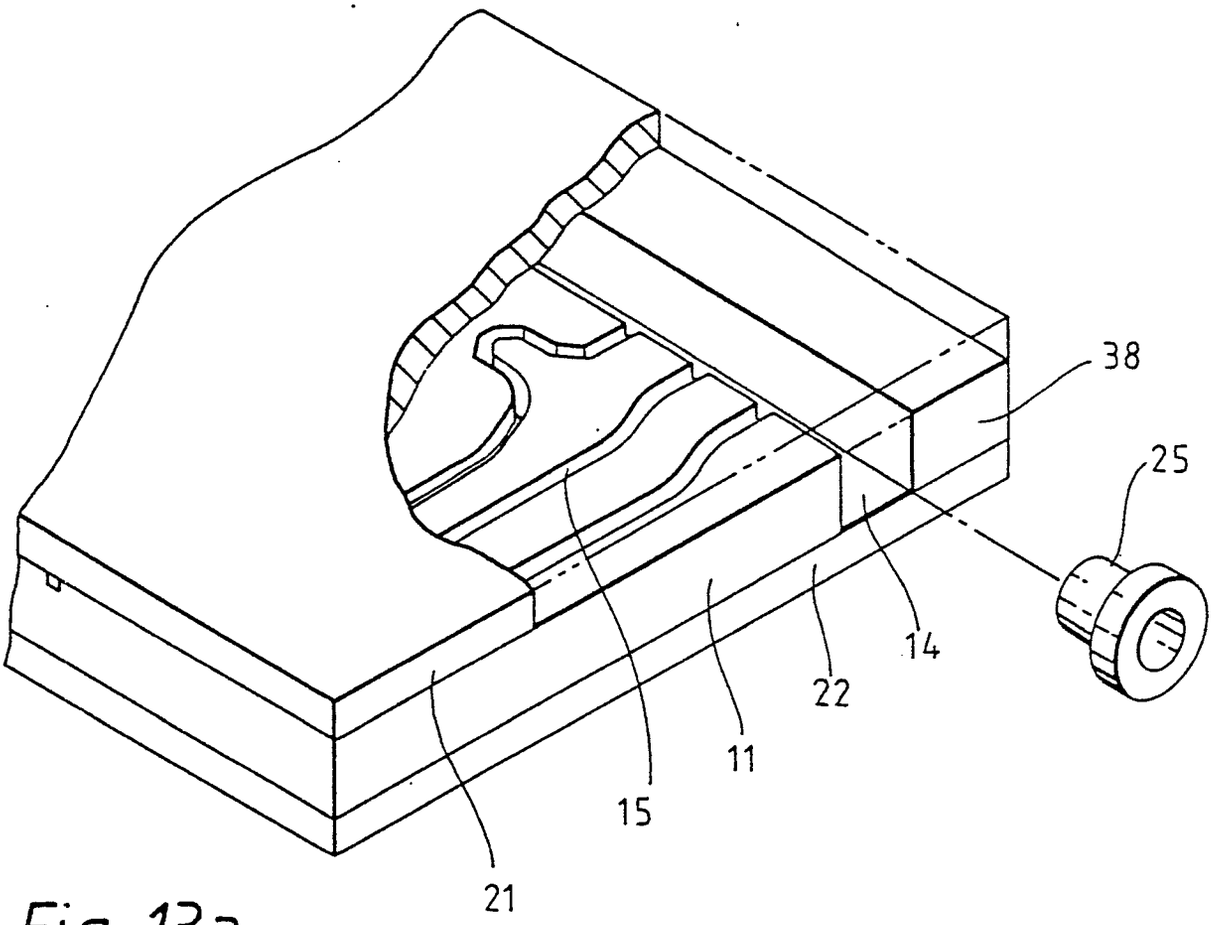

Fig .13a.

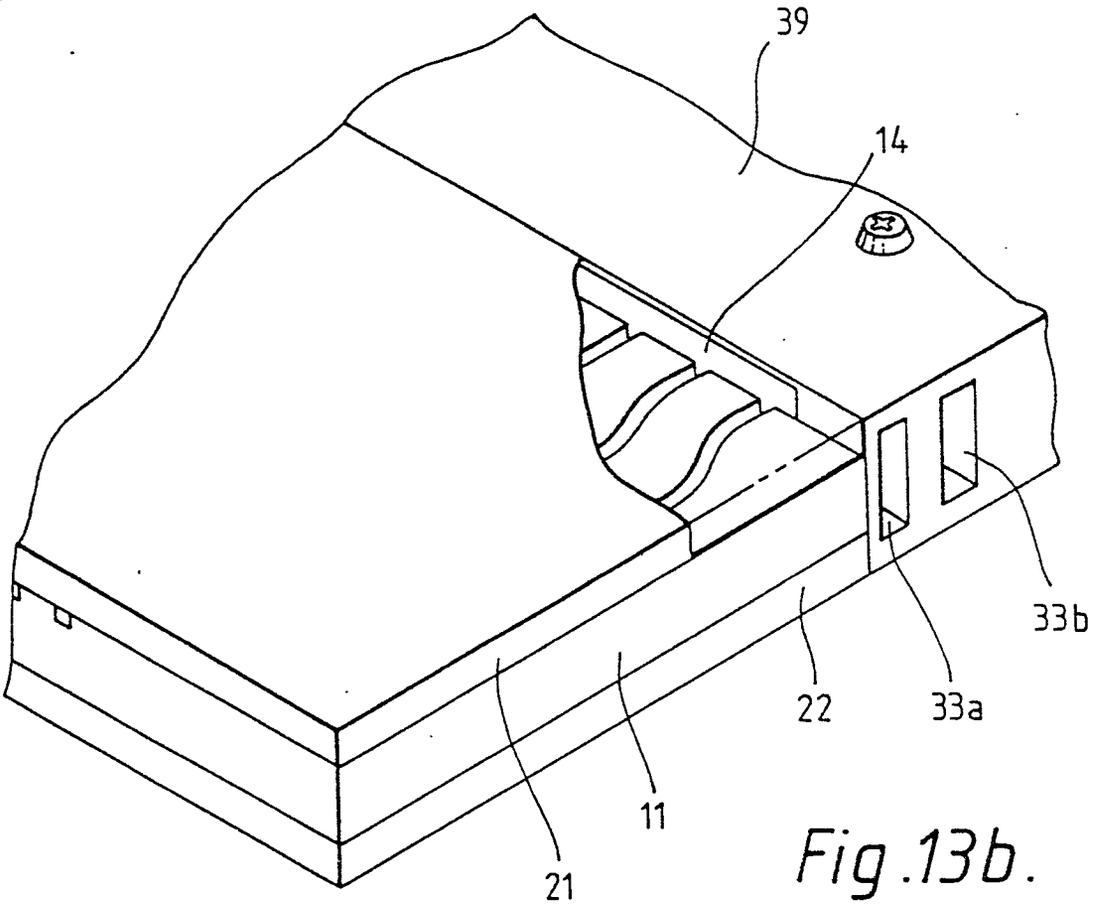

Fig .13b.

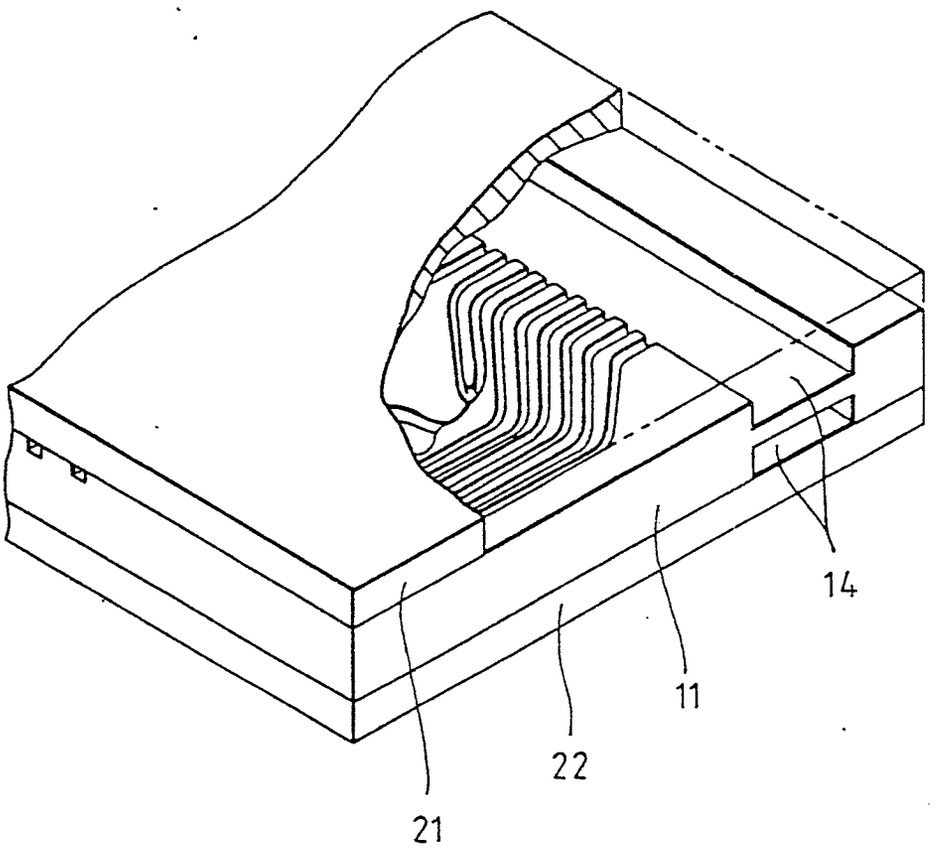

Fig .13c.

0037624

European Patent Office

EUROPEAN SEARCH REPORT

Application number
EP 81300577.4

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim
A	DE - B - 2 233 469 (OLYMPIA)	

CLASSIFICATION OF THE APPLICATION (Int. Cl.³)

B 41 J 3/04

TECHNICAL FIELDS SEARCHED (Int. Cl.³)

B 41 J 3/00
G 06 K 15/00
B 41 F 17/00

CATEGORY OF CITED DOCUMENTS

X: particularly relevant
A: technological background
O: non-written disclosure
P: intermediate document
T: theory or principle underlying the invention
E: conflicting application
D: document cited in the application
L: citation for other reasons

&: member of the same patent family, corresponding document

X The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
VIENNA	21-07-1981	KIENAST