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(54) MAGNETIC-FIELD-ACUTATED INK JET NOZZLE

MAGNETFELD-BETÄTIGTE TINTENSTRAHLDÜSE

BUSE DE JET D'ENCRE, ACTIONNE PAR UN CHAMP MAGNETIQUE

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Description

Field of Invention

[0001] The present invention relates to the field of ink jet printing systems.

Background of the Art

[0002] Many different types of printing have been invented, a large number of which are presently in use. The known forms of print have a variety of methods for marking the print media with a relevant marking media. Commonly used forms of printing induce offset printing, laser printing and copying devices, dot matrix type impact printers, thermal paper printers, film recorders, thermal wax printers, dye sublimation printers and ink jet printers both of the drop on demand and continuous flow type. Each type of printer has its own advantages and problems when considering cost, speed, quality, reliability, simplicity of construction and operation etc.

[0003] In recent years, the field of ink jet printing, wherein each individual pixel of ink is derived from one or more ink nozzles has become increasingly popular primarily due to its inexpensive and versatile nature.

[0004] Many different techniques of ink jet printing have been invented. For a survey of the field, reference is made to an article by J Moore, "Non-Impact Printing: introduction and Historical Perspective", Output Hard Copy Devices, Editors R Dubeck and S Sherr, pages 207 - 220 (1988).

[0005] Ink Jet printers themselves come in many different types. The utilisation of a continuous stream ink in ink jet printing appears to date back to at least 1929 wherein US Patent No. 1941001 by Hansell discloses a simple form of continuous stream electro-static ink jet printing.

[0006] US Patent 3596275 by Sweet also discloses a process of a continuous ink jet printing including the step wherein the ink jet stream is modulated by a high frequency electro-static field so as to cause drop separation. This technique is still utilised by several manufacturers including Elmjet and Scitex (see also US Patent No. 3373437 by Sweet et al)

[0007] Piezo-electric ink jet printers are also one form of commonly utilised ink jet printing device. Piezo-electric systems are disclosed by Kyser et. al. in US Patent No. 3946398 (1970) which utilises a diaphragm mode of operation, by Zolten in US Patent 3683212 (1970) which discloses a squeeze mode of operation of a piezo electric crystal, Stemme in US Patent No. 3747120 (1972) discloses a bend mode of piezo-electric operation, Howkins in US Patent No. 4459601 discloses a Piezo electric push mode actuation of the ink jet stream and Fischbeck in US 4584590 which discloses a sheer mode type of piezo-electric transducer element.

[0008] Recently, thermal ink jet printing has become an extremely popular form of ink jet printing. The ink jet printing techniques include those disclosed by Endo et al in GB 2007162 (1979) and Vaught et al in US Patent 4490728. Both the aforementioned references disclosed ink jet printing techniques rely upon the activation of an electrothermal actuator which results in the creation of a bubble in a constricted space, such as a nozzle, which thereby causes the ejection of ink from an aperture connected to the confined space onto a relevant print media. Printing devices utilising the electro-thermal actuator are manufactured by manufacturers such as Canon and Hewlett Packard.

[0009] As can be seen from the foregoing, many different types of printing technologies are available. Ideally, a printing technology should have a number of desirable attributes. These include inexpensive construction and operation, high speed operation, safe and continuous long term operation etc. Each technology may have its own advantages and disadvantages in the areas of cost, speed, quality, reliability, power usage, simplicity of construction operation, durability and consumables.

[0010] Many ink jet printing mechanisms are known. Unfortunately, in mass production techniques, the production of ink jet heads is quite difficult. For example, often, the orifice or nozzle plate is constructed separately from the ink supply and ink ejection mechanism and bonded to the mechanism at a later stage (Hewlett-Packard Journal, Vol. 36 no 5, pp33-37 (1985)). These separate material processing steps required in handling such precision devices often adds a substantially expense in manufacturing.

[0011] Additionally, side shooting ink jet technologies (U.S. Patent No. 4,899,181) are often used but again, this limit the amount of mass production throughput given any particular capital investment.

[0012] Additionally, more esoteric techniques are also often utilized. These can include electroforming of nickel stage (Hewlett-Packard Journal, Vol. 36 no 5, pp33-37 (1985)), electro-discharge machining, laser ablation (U.S. Patent No. 5,208,604), micro-punching, etc.

[0013] The utilisation of the above techniques is likely to add substantial expense to the mass production of ink jet print heads and therefore add substantially to their final cost.

[0014] It would therefore be desirable if an efficient system for the mass production of ink jet print heads could be developed.

[0015] GB-A-2,262,152 describes a solenoid valve for use in an inkjet printer. The valve comprises an axially elongated body member having a plunger therein for reciprocation along a bore. Motion of the plunger is controlled under the influence of a magnetic field generated by a coil. In use the plunger is used to close an outlet to thereby prevent ink under pressure from being ejected through the outlet. Motion of the plunger can therefore be used to selectively eject ink from the outlet.

[0016] JP-4126255 describes an inkjet print head having a number of electromagnets arranged opposed to each of a number of nozzle openings. A permanent magnet is pressed to the upper end of each electromagnetic coil by a spring. Ink is supplied from the exterior of a frame and filled up to the nozzle opening. When a drive voltage is applied to the electromagnetic coil the permanent magnet and return spring are displaced causing ink to be expelled from the nozzle.

Summary of the invention

[0017] In accordance with a first aspect of the present invention, an ink jet printing nozzle arrangement comprises:

a) a plunger
b) an electric coil located adjacent to the plunger and electrically connected to a nozzle activation signal wherein upon activation of the activation signal, said plunger is caused by said coil to move from an ink loaded position to an ink ejection position thereby causing the ejection of ink from an ink ejection port, characterised in that the arrangement further comprises:

i) a nozzle chamber having the ink ejection port at one end; and,
ii) an ink chamber for allowing for the supply of ink to said nozzle chamber, the plunger being constructed from soft magnetic material and being positioned between the nozzle chamber and the ink chamber.

[0018] The nozzle arrangement typically further comprises an armature plate constructed from soft magnetic material and wherein said plunger is attracted to said armature plate on the activation of said coil.

[0019] The electric coil is usually located within a cavity defined by said plunger and wherein said cavity has its dimensions reduced as a result of movement of said plunger, said plunger further having a series of fluid release slots in fluid communication with said cavity and said ink chamber, said fluid release slots allowing for the expulsion of fluid under pressure in said cavity.

[0020] The slots are typically defined around an inner circumference of said coil and said slots have a substantially constant cross-sectional profile.

[0021] The slots are preferably located in a radial manner on one surface of said plunger.

[0022] The nozzle arrangement preferably further comprises a resilient means for assisting in the return of said plunger from said ink ejection position to said ink loaded position after the ejection of ink from said ink ejection port.

[0023] The resilient means typically comprises a torsional spring.

[0024] The torsional spring is generally of an arcuate construction having a circumferential profile substantially the same as that of said plunger.

[0025] The nozzle apparatus usually further comprises a series of resilient means attached to said magnetic piston so as to return said magnetic piston to said first position upon deactivation of said activation coil.

[0026] The apparatus is generally constructed utilising semi-conductor fabrication techniques.

[0027] The piston and/or said coils are typically constructed from a dual damascene process.

[0028] The ink ejection port typically includes a nozzle rim adapted to reduce hydrophilic surface spreading of said ink.

[0029] The activation coil is generally constructed from a copper deposition process.

[0030] The resilient means can be constructed from silicon nitride.

[0031] The plunger can be substantially circular and has a tapered rim adjacent portions of said electromagnetic device.

[0032] The electromagnetic device is typically of a torus shape and said plunger is located in the center of said torus.

[0033] The plunger is preferably further connected to a resilient means which allows for the return of said plunger to its original position upon deactivation of said electromagnetic device.

[0034] The resilient means may be a series of springs.

[0035] In this case the springs can be interconnedcted to a central portion of said plunger and radially spiral out to said side walls.

[0036] The springs may be formed from tensional release of deposited material.

[0037] The deposited material can include nitride.

Brief Description of the Drawings

[0038] Notwithstanding any other forms which may fall within the scope of the present invention, preferred forms of the invention will now be described, by way of example only, with reference to the accompanying drawings in which:

Fig. 1 is an exploded perspective view illustrating the construction of a single ink jet nozzle in accordance with an embodiment of the present invention;
Fig. 2 is a timing diagram illustrating the operation of an embodiment;
Fig. 3 is a cross-sectional top view of a single ink nozzle constructed in accordance with an embodiment of the present invention;
Fig. 4 provides a legend of the materials indicated in Fig. 5 to Fig. 21;
Fig. 5 to Fig. 21 illustrate sectional views of the manufacturing steps in one form of construction of an ink jet printhead nozzle;
Fig. 22 is an exploded perspective view illustrating the construction of a single ink jet nozzle in accordance with an embodiment of the invention;
Fig. 23 is a perspective view, in part in section, of a single ink jet nozzle constructed in accordance with an embodiment of the invention;
Fig. 24. provides a legend of the materials indicated in Fig. 25 to Fig. 41; and
Fig. 25 to Fig. 41 illustrate sectional views of the manufacturing steps in one form of construction of an ink jet printhead nozzle.
Fig. 42 is a perspective cross-sectional view of a single ink jet nozzle constructed in accordance with an embodiment of the invention;
Fig. 43 is an exploded perspective view illustrating the construction of a single ink jet nozzle in accordance with an embodiment of the invention;
Fig. 44 provides a legend of the materials indicated in Fig. 45 to Fig. 63; and
Fig. 45 to Fig. 63 illustrate sectional views of the manufacturing steps in one form of construction of an ink jet printhead nozzle.

Description of the Preferred and Other Embodiments

[0039] The preferred embodiments and other embodiments will be discussed under separate headings with the heading including an IJ number for ease of reference. The headings also include a type designator with T indicating thermal, S indicating shutter type and F indicating a field type.

Description of IJO1 F

[0040] In Fig. 1, there is illustrated an exploded perspective view illustrating the construction of a single ink jet nozzle 4 in accordance with the principles of the present invention.

[0041] The nozzle 4 operates on the principle of electro-mechanical energy conversion and comprises a solenoid 11 which is connected electrically at a first end 12 to a magnetic plate 13 which is in turn connected to a current source e.g. 14 utilized to activate the ink nozzle 4. The magnetic plate 13 can be constructed from electrically conductive iron.

[0042] A second magnetic plunger 15 is also provided, again being constructed from soft magnetic iron. Upon energizing the solenoid 11, the plunger 15 is attracted to the fixed magnetic plate 13. The plunger thereby pushes against the ink within the nozzle 4 creating a high pressure zone in the nozzle chamber 17. This causes a movement of the ink in the nozzle chamber 17 and in a first design, subsequent ejection of an ink drop. A series of apertures e.g. 20 is provided so that ink in the region of solenoid 11 is squirted out of the holes 20 in the top of the plunger 15 as it moves towards lower plate 13. This prevents ink trapped in the area of solenoid 11 from increasing the pressure on the plunger 15 and thereby increasing the magnetic forces needed to move the plunger 15.

[0043] Referring now to Fig. 2, there is illustrated 30 a timing diagram of the plunger current control signal. Initially, the solenoid current is activated 31 for the movement of the plunger and ejection of a drop from the ink nozzle. After approximately 2 micro-seconds, the current to the solenoid is turned off. At the same time or at a slightly later time 32, a reverse current is applied having approximately half the magnitude of the forward current. As the plunger has a residual magnetism, the reverse current 32 causes the plunger to move backwards towards its original position. A series of torsional springs 22, 23 (Fig. 1) also assists in the return of the plunger to its original position. The reverse current is turned off before the magnetism of the plunger 15 is reversed which would otherwise result in the plunger being attracted to the fixed plate again. Returning to Fig. 1, the forced return of the plunger 15 to its quiescent position results in a low pressure in the chamber 17. This can cause ink to begin flowing from the outlet nozzle 24 inwards and also ingests air to the chamber 17. The forward velocity of the drop and the backward velocity of the ink in the chamber

17 are resolved by the ink drop breaking off around the nozzle 24. The ink drop then continues to travel toward the recording medium under its own momentum. The nozzle refills due to the surface tension of the ink at the nozzle tip 24. Shortly after the time of drop break off, a meniscus at the nozzle tip is formed with an approximately a concave hemispherical surface. The surface tension will exert a net forward force on the ink which will result in nozzle refilling. The repetition rate of the nozzle 4 is therefore principally determined by the nozzle refill time which will be 100micro-seconds, depending on the device geometry, ink surface tension and the volume of the ejected drop.

[0044] Turning now to Fig. 3, an important aspect of the operation of the electro-magnetically driven print nozzle will now be described. Upon a current flowing through the coil 11, the plate 15 becomes strongly attracted to the plate 13. The plate 15 experiences a downward force and begins movement towards the plate 13. This movement imparts a momentum to the ink within the nozzle chamber 17. The ink is subsequently ejected as hereinbefore described. Unfortunately, the movement of the plate 15 causes a build-up of pressure in the area 64 between the plate 15 and the coil 11. This build-up would normally result in a reduced effectiveness of the plate 15 in ejecting ink.

[0045] However, in a first design the plate 15 preferably includes a series of apertures e.g. 20 which allow for the flow of ink from the area 64 back into the ink chamber and thereby allow a reduction in the pressure in area 64. This results in an increased effectiveness in the operation of the plate 15.

[0046] Preferably, the apertures 20 are of a teardrop shape increasing in diameter with increasing radial distance of the plunger. The aperture profile thereby providing minimal disturbance of the magnetic flux through the plunger while maintaining structural integrity of plunger 15.

[0047] After the plunger 15 has reached its end position, the current through coil 11 is reversed resulting in a repulsion of the two plates 13, 15. Additionally, the torsional spring e.g. 23 acts to return the plate 15 to its initial position.

[0048] The use of a torsional spring e.g. 23 has a number of substantial benefits including a compact layout, and the construction of the torsional spring from the same material and same processing steps as that of the plate 15.

[0049] In an alternative design, the top surface of plate 15 does not include a series of apertures. Rather, the inner radial surface 25 of plate 15 comprises slots of substantially constant cross-sectional profile in fluid communication between the nozzle chamber 17 and the area 64 between plate 15 and the solenoid 11. Upon activation of the coil 11, the plate 15 is attracted to the armature plate 13 and experiences a force directed towards plate 13. As a result of the movement, fluid in the area 64 is compressed and experiences a higher pressure than its surrounds. As a result, the flow of fluid takes place out of the slots in the inner radial surface 25 plate 15 into the nozzle chamber 17. The flow of fluid into chamber 17, in addition to the movement of the plate 15, causes the ejection of ink out of the ink nozzle port 24. Again, the movement of the plate 15 causes the torsional springs, for example 23, to be resiliently deformed. Upon completion of the movement of the plate 15, the coil 11 is deactivated and a slight reverse current is applied. The reverse current acts to repel the plate 15 from the armature plate 13. The torsional springs, for example 23, act as additional means to return the plate 15 to its initial or quiescent position.

Fabrication

[0050] Returning now to Fig. 1, the nozzle apparatus is constructed from the following main parts including a nozzle tip 40 having an aperture 24 which can be constructed from boron doped silicon. The radius of the aperture 24 of the nozzle tip is an important determinant of drop velocity and drop size.

[0051] Next, a CMOS silicon layer 42 is provided upon which is fabricated all the data storage and driving circuitry 41 necessary for the operation of the nozzle 4. In this layer a nozzle chamber 17 is also constructed. The nozzle chamber 17 should be wide enough so that viscous drag from the chamber walls does not significantly increase the force required of the plunger. It should also be deep enough so that any air ingested through the nozzle port 24 when the plunger returns to its quiescent state does not extend to the plunger device. If it does, the ingested bubble may form a cylindrical surface instead of a hemispherical surface resulting in the nozzle not refilling properly. A CMOS dielectric and insulating layer containing various current paths parts for the current connection to the plunger device is also provided 44.

[0052] Next, a fixed plate of ferroelectric material is provided having two parts 13, 46. The two parts 13, 46 are electrically insulated from one another.

[0053] Next, a solenoid 11 is provided. This can comprise a spiral coil of deposited copper. Preferably a single spiral layer is utilized to avoid fabrication difficulty and copper is used for a low resistivity and high electro-migration resistance.

[0054] Next, a plunger 15 of ferromagnetic material is provided to maximize the magnetic force generated. The plunger 15 and fixed magnetic plate 13, 46 surround the solenoid 11 as a torus. Thus, little magnetic flux is lost and the flux is concentrated around the gap between the plunger 15 and the fix plate 13, 46.

[0055] The gap between the fixed plate 13, 46 and the plunger 15 is one of the most important "parts" of the print nozzle 4. The size of the gap will strongly affect the magnetic force generated, and also limits the travel of the plunger 15. A small gap is desirable to achieve a strong magnetic force, but a large gap is desirable to allow longer plunger 15 to travel, and therefore allow smaller plunger radius to be utilized.

[0056] Next, the springs, e.g. 22, 23 for returning to the plunger 15 to its quiescent position after a drop has been ejected are provided. The springs, e.g. 22, 23 can be fabricated from the same material, and in the same processing step, as the plunger 15. Preferably the springs, e.g. 22, 23 act as torsional springs in their interaction with the plunger 15.

[0057] Finally, all surfaces are coated with passivation layers, which may be silicon nitride (Si_3N_4), diamond like carbon (DLC), or other chemically inert, highly impermeable layer. The passivation layers are especially important for device lifetime, as the active device will be immersed in the ink.

[0058] One form of detailed manufacturing process which can be used to fabricate monolithic ink jet print heads operating in accordance with the principles taught by the present embodiment can proceed utilizing the following steps:

1. Using a double sided polished water deposit 3 microns of epitaxial silicon heavily doped with boron.
2. Deposit 10 microns of epitaxial silicon, either p-type or n-type, depending upon the CMOS process used.
3. Complete a 0.5 micron, one poly, 2 metal CMOS process. This step is shown in Fig. 5. For clarity, these diagrams may not be to scale, and may not represent a cross section though any single plane of the nozzle. Fig. 4 is a key to representations of various materials in these manufacturing diagrams, and those of other cross referenced ink jet configurations.
4. Etch the CMOS oxide layers down to silicon or aluminum using Mask 1. This mask defines the nozzle chamber, the edges of the print heads chips, and the vias for the contacts from the aluminum electrodes to the two halves of the split fixed magnetic plate.
5. Plasma etch the silicon down to the boron doped buried layer, using oxide from step 4 as a mask. This etch does not substantially etch the aluminum. This step is shown in Fig. 6.
6. Deposit a seed layer of cobalt nickel iron alloy. CoNiFe is chosen due to a high saturation flux density of 2 Tesla, and a low coercivity. [Osaka, Tetsuya et al, A soft magnetic CoNiFe film with high saturation magnetic flux density, Nature 392, 796-798 (1998)].
7. Spin on 4 microns of resist, expose with Mask 2, and develop. This mask defines the split fixed magnetic plate, for which the resist acts as an electroplating mold. This step is shown in Fig. 7.
8. Electroplate 3 microns of CoNiFe. This step is shown in Fig. 8.
9. Strip the resist and etch the exposed seed layer. This step is shown in Fig. 9.
10. Deposit 0.1 microns of silicon nitride (Si_3N_4).
11. Etch the nitride layer using Mask 3. This mask defines the contact vias from each end of the solenoid coil to the two halves of the split fixed magnetic plate.
12. Deposit a seed layer of copper. Copper is used for its low resistivity (which results in higher efficiency) and its high electromigration resistance, which increases reliability at high current densities.
13. Spin on 5 microns of resist, expose with Mask 4, and develop. This mask defines the solenoid spiral coil and the spring posts, for which the resist acts as an electroplating mold. This step is shown in Fig. 10.
14. Electroplate 4 microns of copper.
15. Strip the resist and etch the exposed copper seed layer. This step is shown in Fig. 11.
16. Wafer probe. All electrical connections are complete at this point, bond pads are accessible, and the chips are not yet separated.
17. Deposit 0.1 microns of silicon nitride.
18. Deposit 1 micron of sacrificial material. This layer determines the magnetic gap.
19. Etch the sacrificial material using Mask 5. This mask defines the spring posts. This step is shown in Fig. 12.
20. Deposit a seed layer of CoNiFe.
21. Spin on 4.5 microns of resist, expose with Mask 6, and develop. This mask defines the walls of the magnetic plunger, plus the spring posts. The resist forms an electroplating mold for these parts. This step is shown in Fig. 13.
22. Electroplate 4 microns of CoNiFe. This step is shown in Fig. 14.
23. Deposit a seed layer of CoNiFe.
24. Spin on 4 microns of resist, expose with Mask 7, and develop. This mask defines the roof of the magnetic plunger, the springs, and the spring posts. The resist forms an electroplating mold for these parts. This step is shown in Fig. 15.
25. Electroplate 3 microns of CoNiFe. This step is shown in Fig. 16.
26. Mount the wafer on a glass blank and back-etch the wafer using KOH, with no mask. This etch thins the wafer and stops at the buried boron doped silicon layer. This step is shown in Fig. 17.
27. Plasma back-etch the boron doped silicon layer to a depth of (approx.) 1 micron using Mask 8. This mask defines the nozzle rim. This step is shown in Fig. 18.
28. Plasma back-etch through the boron doped layer using Mask 9. This mask defines the nozzle, and the edge of the chips. At this stage, the chips are separate, but are still mounted on the glass blank. This step is shown in Fig. 19.
29. Detach the chips from the glass blank. Strip all adhesive, resist, sacrificial, and exposed seed layers. This step

is shown in Fig. 20.

30. Mount the print heads in their packaging, which may be a molded plastic former incorporating ink channels which supply different colors of ink to the appropriate regions of the front surface of the wafer.

31. Connect the print heads to their interconnect systems.

32. Hydrophobize the front surface of the print heads.

33. Fill the completed print heads with ink and test them. A filled nozzle is shown in Fig. 21.

Description of IJ05 F

[0059] An embodiment of the present invention relies upon the utilisation of a magnetic actuator to "load" a spring, such that, upon deactivation of the magnetic actuator the resultant movement of the spring causes ejection of a drop of ink as the spring returns to its original position.

[0060] Turning to Fig. 22, there is illustrated an exploded perspective view of an ink nozzle arrangement 401 constructed in accordance with an embodiment. It would be understood that an embodiment can be constructed as an array of nozzle arrangements 401 so as to together form a line for printing.

[0061] The operation of the ink nozzle arrangement 401 of Fig. 22 proceeds by a solenoid 402 being energized by way of a driving circuit 403 when it is desired to print out a ink drop. The energized solenoid 402 induces a magnetic field in a fixed soft magnetic pole 404 and a moveable soft magnetic pole 405. The solenoid power is turned on to a maximum current for long enough to move the moveable pole 405 from its rest position to a stopped position close to the fixed magnetic pole 404. The ink nozzle arrangement 401 of Fig. 59 sits within an ink chamber filled with ink. Therefore, holes 406 are provided in the moveable soft magnetic pole 405 for "squirting" out of ink from around the coil 402 when the plate 405 undergoes movement.

[0062] The moveable sort magnetic pole is balanced by a fulcrum 408 with a piston head 409. Movement of the magnetic pole 405 closer to the stationary pole 404 causes the piston head 409 to move away from a nozzle chamber 411 drawing air into the chamber 411 via an ink ejection port 413. The piston 409 is then held open above the nozzle chamber 411 by means of maintaining a low "keeper" current through solenoid 402. The keeper level current through solenoid 402 being sufficient to maintain the moveable pole 405 against the fixed soft magnetic pole 404. The level of current will be substantially less than the maximum current level because the gap between the two poles 404 and 405 is at a minimum. For example, a keeper level current of 10% of the maximum current level may be suitable. During this phase of operation, the meniscus of ink at the nozzle tip or ink ejection port 413 is a concave hemisphere due to the in flow of air. The surface tension on the meniscus exerts a net force on the ink which results in ink flow from the ink chamber into the nozzle chamber 411. This results in the nozzle chamber refilling, replacing the volume taken up by the piston head 409 which has been withdrawn. This process takes approximately 100 μs.

[0063] The current within solenoid 402 is then reversed to half that of the maximum current. The reversal demagnetizes the magnetic poles and initiates a return of the piston 409 to its rest position. The piston 409 is moved to its normal rest position by both the magnetic repulsion and by the energy stored in a stressed torsional spring 416,419 which was put in a state of torsion upon the movement of moveable pole 405.

[0064] The forces applied to the piston 409 as a result of the reverse current and spring 416,419 will be greatest at the beginning of the movement of the piston 409 and will decrease as the spring elastic stress falls to zero. As a result, the acceleration of piston 409 is high at the beginning of a reverse stroke and the resultant ink velocity within the chamber 411 becomes uniform during the stroke. This results in an increased operating tolerance before ink flow over the print head surface will occur.

[0065] At a predetermined time during the return stroke, the solenoid reverse current is turned off. The current is turned off when the residual magnetism of the movable pole is at a minimum. The piston 409 continues to move towards its original rest position.

[0066] The piston 409 will overshoot the quiescent or rest position due to its inertia. Overshoot in the piston movement achieves two things: greater ejected drop volume and velocity, and improved drop break off as the piston returns from overshoot to its quiescent position.

[0067] The piston 409 will eventually return from overshoot to the quiescent position. This return is caused by the springs 416, 419 which are now stressed in the opposite direction. The piston return "sucks" some of the ink back into the nozzle chamber 411, causing the ink ligament connecting the ink drop to the ink in the nozzle chamber 411 to thin. The forward velocity of the drop and the back ward velocity of the ink in the nozzle chamber 411 are resolved by the ink drop breaking off from the ink in the nozzle chamber 411.

[0068] The piston 409 stays in the quiescent position until the next drop ejection cycle.

[0069] A liquid ink print head has one ink nozzle arrangement 401 associated with each of the multitude of nozzles. The arrangement 401 has the following major parts:

(1) Drive circuitry 403 for driving the solenoid 402.

(2) A nozzle tip 413. The radius of the nozzle tip 413 is an important determinant of drop velocity and drop size.
(3) A piston 404. This is a cylinder which moves through the nozzle chamber 411 to expel the ink. The piston 409 is connected to one end of the lever arm 417. The piston radius is approximately 1.5 to 2 times the radius of the hole 413. The ink drop volume output is mostly determined by the volume of ink displaced by the piston 409 during the piston return stroke.
(4) A nozzle chamber 411. The nozzle chamber 411 is slightly wider than the piston 409. The gap between the piston 409 and the nozzle chamber walls is as small as is required to ensure that the piston does not contact the nozzle chamber during actuation or return. If the print heads are fabricated using 0.5 μm semiconductor lithography, then a 1 μm gap will usually be sufficient. The nozzle chamber is also deep enough so that air ingested through the nozzle tip 413 when the plunger 409 returns to its quiescent state does not extend to the piston 409. If it does, the ingested bubble may form a cylindrical surface instead of a hemispherical surface. If this happens, the nozzle will not refill properly.
(5) A solenoid 402. This is a spiral coil of copper. Copper is used for its low resistivity, and high electro-migration resistance.
(6) A fixed magnetic pole of ferromagnetic material 404.
(7) A moveable magnetic pole of ferromagnetic material 405. To maximize the magnetic force generated, the moveable magnetic pole 405 and fixed magnetic pole 404 surround the solenoid 402 as a torus. Thus little magnetic flux is lost, and the flux is concentrated across the gap between the moveable magnetic pole 405 and the fixed pole 404. The moveable magnetic pole 405 has holes in the surface 406 (Fig. 22) above the solenoid to allow trapped ink to escape. These holes are arranged and shaped so as to minimize their effect on the magnetic force generated between the moveable magnetic pole 405 and the fixed magnetic pole 404.
(8) A magnetic gap. The gap between the fixed plate 404 and the moveable magnetic pole 405 is one of the most important "parts" of the print actuator. The size of the gap strongly affects the magnetic force generated, and also limits the travel of the moveable magnetic pole 405. A small gap is desirable to achieve a strong magnetic force. The travel of the piston 409 is related to the travel of the moveable magnetic pole 405 (and therefore the gap) by the lever arm 417.
(9) Length of the lever arm 417. The lever arm 417 allows the travel of the piston 409 and the moveable magnetic pole 405 to be independently optimized. At the short end of the lever arm 417 is the moveable magnetic pole 405. At the long end of the lever arm 417 is the piston 409. The spring 416 is at the fulcrum 408. The optimum travel for the moveable magnetic pole 405 is less than 1 micron, so as to minimize the magnetic gap. The optimum travel for the piston 409 is approximately 405 μm for a 1200 dpi printer. The difference in optimum travel is resolved by a lever 417 with a 5:1 or greater ratio in arm length.
(10) Springs 416, 419 (Fig. 22). The springs e.g. 416 return the piston to its quiescent position after a deactivation of the actuator. The springs 416 are at the fulcrum 408 of the lever arm.
(11) Passivation layers (not shown). Al surfaces are preferably coated with passivation layers, which may be silicon nitride (Si_3N_4), diamond like carbon (DLC), or other chemically inert, highly impermeable layer. The passivation layers are especially important for device lifetime, as the active device is immersed in the ink. As will be evident from the foregoing description there is an advantage in ejecting the drop on deactivation of the solenoid 402. This advantage comes from the rate of acceleration of the moving magnetic pole 405 which is used as a piston or plunger.

[0070] The force produced by a moveable magnetic pole by an electromagnetic induced field is approximated proportional to the inverse square of the gap between the moveable 405 and static magnetic poles 404. When the solenoid 402 is off, this gap is at a maximum. When the solenoid 402 is turned on, the moving pole 405 is attracted to the static pole 404. As the gap decreases, the force increases, accelerating the movable pole 405 faster. The velocity increases in a highly non-linear fashion, approximately with the square of time. During the reverse movement of the moving pole 405 upon deactivation the acceleration of the moving pole 405 is greatest at the beginning and then slows as the spring elastic stress falls to zero. As a result, the velocity of the moving pole 405 is more uniform during the reverse stroke movement.

(1) The velocity of piston or plunger 409 is much more constant over the duration of the drop ejection stroke.
(2) The piston or plunger 409 can readily be entirely removed from the ink chamber during the ink fill stage, and thereby the nozzle filling time can be reduced, allowing faster print head operation.

[0071] However, this approach does have some disadvantages over a direct firing type of actuator:

(1) The stresses on the spring 416 are relatively large. Careful design is required to ensure that the springs operate at below the yield strength of the materials used.
(2) The solenoid 402 must be provided with a "keeper" current for the nozzle fill duration. The keeper current will

typically be less than 10% of the solenoid actuation current. However, the nozzle fill duration is typically around 50 times the drop firing duration, so the keeper energy will typically exceed the solenoid actuation energy.
(3) The operation of the actuator is more complex due to the requirement for a "keeper" phase.

[0072] The print head is fabricated from two silicon wafers. A first wafer is used to fabricate the print nozzles (the print head wafer) and a second wafer (the Ink Channel Wafer) is utilized to fabricate the various ink channels in addition to providing a support means for the first channel. The fabrication process then proceeds as follows:

(1) Start with a single crystal silicon wafer 420, which has a buried epitaxial layer 422 of silicon which is heavily doped with boron. The boron should be doped to preferably 10^{20} atoms per cm^3 of boron or more, and be approximately 3 μm thick, and be doped in a manner suitable for the active semiconductor device technology chosen. The wafer diameter of the print head wafer should be the same as the ink channel wafer.
(2) Fabricate the drive transistors and data distribution circuitry 403 according to the process chosen (e.g. CMOS).
(3) Planarise the wafer 420 using chemical Mechanical Planarisation (CMP).
(4) Deposit 5 micron of glass (SiO_2) over the second level metal.
(5) Using a dual damascene process, etch two levels into the top oxide layer. Level 1 is 4 μm deep, and level 2 is 5 μm deep. Level 2 contacts the second level metal. The masks for the static magnetic pole are used.
(6) Deposit 5 μm of nickel iron alloy (NiFe).
(7) Planarise the wafer using CMP, until the level of the SiO_2 is reached forming the magnetic pole 404.
(8) Deposit 0.1 μm of silicom nitride (Si_3N_4).
(9) Etch the Si_3N_4 for via holes for the connections to the solenoids, and for the nozzle chamber region 411.
(10) Deposit 4 μm of SiO_2.
(11) Plasma etch the SiO_2 in using the solenoid and support post mask.
(12) Deposit a thin diffusion barrier, such as Ti, TiN, or TiW, and an adhesion layer if the diffusion layer chosen has insufficient adhesion.
(13) Deposit 4 μm of copper for forming the solenoid 402 and spring posts 424. The deposition may be by sputtering, CVD, or electroless plating. As well as lower resistivity than aluminum, copper has significantly higher resistance to electro-migration. The electro-migration resistance is significant, as current densities in the order of 3 x 106 $Amps/cm^2$ may be required. Copper films deposited by low energy kinetic ion bias sputtering have been found to have 1,000 to 100,000 times larger electro-migration lifetimes larger than aluminum silicon alloy. The deposited copper should be alloyed and layered for maximum electro-migration lifetimes than aluminum silicon alloy. The deposited copper should be alloyed and layered for maximum electro-migration resistance, while maintaining high electrical conductivity.
(14) Planarise the wafer using CMP, until the level of the SiO_2 is reached. A damascene process is used for the copper layer due to the difficulty involved in etching copper. However, since the damascene dielectric layer is subsequently removed, processing is actually simpler if a standard deposit/etch cycle is used instead of damascene. However, it should be noted that the aspect ratio of the copper etch would be 8:1 for this design, compared to only 4:1 for a damascene oxide etch. This difference occurs because the copper is 1 μm wide and 4 μm thick, but has only 0.5 μm spacing. Damascene processing also reduces the lithographic difficulty, as the resist is on oxide, not metal.
(15) Plasma etch the nozzle chamber 411, stopping at the boron doped epitaxial silicon layer 421. This etch will be through around 13 μm of SiO_2, and 8 μm of silicon. The etch should be highly anisotropic, with near vertical sidewalls. The etch stop detection can be on boron in the exhaust gasses. If this etch is selective against NiFe, the masks for this step and the following step can be combined, and the following step can be eliminated. This step also etches the edge of the print head wafer down to the boron layer, for later separation.
(16) Etch the SiO_2 layer. This need only be removed in the regions above the NiFe fixed magnetic poles, so it can be removed in the previous step if an Si and SiO_2 etch selective against NiFe is used.
(17) Conformably deposit 0.5 μm of high density Si_3N_4. This forms a corrosion barrier, so should be free of pinholes, and be impermeable to OH ions.
(18) Deposit a thick sacrificial layer 440. This layer should entirety fill the nozzle chambers, and coat the entire wafer to an added thickness of 8 μm. The sacrificial layer may be SiO_2.
(19) Etch two depths in the sacrificial layer for a dual damascene process. The deep etch is 8 μm, and the shallow etch is 3 μm. The masks defines the piston 409, the lever arm 417, the springs 416 and the moveable magnetic pole 405.
(20) Conformably deposit 0.1 μm of high density Si_3N_4. This forms a corrosion barrier, so should be free of pinholes, and be impermeable to OH ions.
(21) Deposit 8 μm of nickel iron alloy (NiFe).
(22) Planarise the wafer using CMP, until the level of the SiO_2 is reached.

(23) Deposit 0.1 μm of silicon nitride (Si_3N_4).
(24) Etch the Si_3N_4 everywhere except the top of the plungers.
(25) Open the bond pads.
(26) Permanently bond the wafer onto a pre-fabricated ink channel wafer. The active side of the print head wafer faces the ink channel wafer. The ink channel wafer is attached to a backing plate, as it has already been etched into separate ink channel chips.
(27) Etch the print head wafer to entirely remove the backside silicon to the level of the boron doped epitaxial layer 422. This etch can be a batch wet etch in ethylenediamine pyrocatechol (EDP).
(28) Mask the nozzle rim 414 from the underside of the print head wafer. This mask also includes the chip edges.
(31) Etch through the boron doped silicon layer 422, thereby creating the nozzle holes. This etch should also etch fairly deeply into the sacrificial material in the nozzle chambers to reduce time required to remove the sacrificial layer.
(32) Completely etch the sacrificial material. If this material is SiO_2 then a HF etch can be used. The nitride coating on the various layers protects the other glass dielectric layers and other materials in the device from HF etching. Access of the HF to the sacrificial layer material is through the nozzle, and simultaneously through the ink channel chip. The effective depth of the etch is 21 μm.
(33) Separate the chips from the backing plate. Each chip is now a full print head including ink channels. The two wafers have already been etched through, so the print heads do not need to be diced.
(34) Test the print heads and TAB bond the good print heads.
(35) Hydrophobise the front surface of the print heads.
(36) Perform final testing on the TAB bonded print heads.

[0073] Fig. 23 shows a perspective view, in part in section, of a single ink jet nozzle arrangement 401 constructed in accordance with an embodiment.

[0074] One alternative form of detailed manufacturing process which can be used to fabricate monolithic ink jet print heads operating in accordance with the principles taught by the present embodiment can proceed utilizing the following steps:

1. Using a double sided polished wafer deposit 3 microns of epitaxial silicon heavily doped with boron.
2. Deposit 10 microns of epitaxial silicon, either p-type or n-type, depending upon the CMOS process used.
3. Complete a 0.5 micron, one poly, 2 metal CMOS process. This step is shown in Fig. 25. For clarity, these diagrams may not be to scale, and may not represent a cross section though any single plane of the nozzle. Fig. 24 is a key to representations of various materials in these manufacturing diagrams.
4. Etch the CMOS oxide layers down to silicon or aluminum using Mask 1. This mask defines the nozzle chamber, the edges of the print heads chips, and the vias for the contacts from the aluminum electrodes to the two halves of the split fixed magnetic plate.
5. Plasma etch the silicon down to the boron doped buried layer, using oxide from step 4 as a mask. This etch does not substantially etch the aluminum. This step is shown in Fig. 26.
6. Deposit a seed layer of cobalt nickel iron alloy. CoNiFe is chosen due to a high saturation flux density of 2 Tesla, and a low coercivity. [Osaka, Tetsuya et al, A soft magnetic CoNiFe film with high saturation magnetic flux density, Nature 392, 796-798 (1998)].
7. Spin on 4 microns of resist, expose with Mask 2, and develop. This mask defines the split fixed magnetic plate and the nozzle chamber wall, for which the resist acts as in electroplating mold. This step is shown in Fig. 27.
8. Electroplate 3 microns of CoNiFe. This step is shown in Fig. 28.
9. Strip the resist and etch the exposed seed layer. This step is shown in Fig. 29.
10. Deposit 0.1 microns of silicon nitride (Si_3N_4).
11. Etch the nitride layer using Mask 3. This mask defines the contact vias from each end of the solenoid coil to the two halves of the split fixed magnetic plate.
12. Deposit a seed layer of copper. Copper is used for its low resistivity (which results in higher efficiency) and its high electromigration resistance, which increases reliability at high current densities.
13. Spin on 5 microns of resist, expose with Mask 4, and develop. This mask defines the solenoid spiral coil, the nozzle chamber wall and the spring posts, for which the resist acts as an electroplating mold. This step is shown in Fig. 30.
14. Electroplate 4 microns of copper.
15. Strip the resist and etch the exposed copper seed layer. This step is shown in Fig. 31.
16. Wafer probe. All electrical connections are complete at this point, bond pads are accessible, and the chips are not yet separated.
17. Deposit 0.1 microns of silicon nitride.

18. Deposit 1 micron of sacrificial material. This layer determines the magnetic gap.
19. Etch the sacrificial material using Mask 5. This mask defines the spring posts and the nozzle chamber wall. This step is shown in Fig. 32.
20. Deposit a seed layer of CoNiFe.
21. Spin on 4.5 microns of resist, expose with Mask 6, and develop. This mask defines the walls of the magnetic plunger, the lever arm, the nozzle chamber wall and the spring posts. The resist forms an electroplating mold for these parts. This step is shown in Fig. 33.
22. Electroplate 4 microns of CoNiFe. This step is shown in Fig. 34.
23. Deposit a seed layer of CoNiFe.
24. Spin on 4 microns of resist, expose with Mask 7, and develop. This mask defines the roof of the magnetic plunger, the nozzle chamber wall, the lever arm, the springs, and the spring posts. The resist forms an electroplating mold for these parts. This step is shown in Fig. 35.
25. Electroplate 3 microns of CoNiFe. This step is shown in Fig. 36.
26. Mount the wafer on a glass blank and back-etch the wafer using KOH, with no mask. This etch thins the wafer and stops at the buried boron doped silicon layer. This step is shown in Fig. 37.
27. Plasma back-etch the boron doped silicon layer to a depth of 1 micron using Mask 8. This mask defines the nozzle rim. This step is shown in Fig. 38.
28. Plasma back-etch through the boron doped layer using Mask 9. This mask defines the nozzle, and the edge of the chips. At this stage, the chips are separate, but are still mounted on the glass blank. This step is shown in Fig. 39.
29. Detach the chips from the glass blank. Strip all adhesive, resist, sacrificial, and exposed seed layers. This step is shown in Fig. 40.
30. Mount the print heads in their packaging, which may be a molded plastic former incorporating ink channels which supply different colors of ink to the appropriate regions of the front surface of the wafer.
31. Connect the print heads to their interconnect systems.
32. Hydrophobize the front surface of the print heads.
33. Fill the completed print heads with ink and test them. A filled nozzle is shown in Fig. 41.

Description of IJ14 F

[0075] In an embodiment, there is provided an ink jet nozzle which incorporates a plunger that is surrounded by an electromagnetic device. The plunger is made from a magnetic material such that upon activation of the magnetic device, the plunger is forced towards a nozzle outlet port thereby resulting in the ejection of ink from the outlet port. Upon deactivation of the electromagnet, the plunger returns to its rest position via the utilisation of a series of springs constructed to return the electromagnet to its rest position.

[0076] Fig. 42 illustrates a sectional view through a single ink jet nozzle 1310 as constructed with an embodiment. The ink jet nozzle 1310 includes a nozzle chamber 1311 which is connected to a nozzle output port 1312 for the ejection of ink. The ink is ejected by means of a tapered plunger device 1314 which is made of a soft magnetic material such as nickel-ferrous material (NIFE). The plunger 1314 includes tapered end portions, e.g. 1316, in addition to interconnecting nitride springs, e.g. 1317.

[0077] An electromagnetic device is constructed around the plunger 1314 and includes outer soft magnetic material 1319 which surrounds a copper current carrying wire core 1320 with a first end of the copper coil 1320 connected to a first portion of a nickel- ferrous material and a second end of the copper coil is connected to a second portion of the nickel-ferrous material. The circuit being further formed by means of vias (not shown) connecting the current carrying wire to lower layers which can take the structure of standard CMOS fabrication layers.

[0078] Upon activation of the electromagnet, the tapered plunger portions 1316 attracted to the electromagnet. The tapering allows for the forces to be resolved by means of downward movement of the overall plunger 1314, the downward movement thereby causing the ejection of ink from ink ejection port 1312. In due course, the plunger will move to a stable state having a top surface substantially flush with the electromagnet. Upon turning the power off, the plunger 1314 will return to its original position as a result of energy stored within that nitride springs 1317. The nozzle chamber 1311 is refilled by inlet holes 1322 from the ink reservoir 1323.

[0079] Turning now to Fig. 43, there is illustrated an exploded perspective of the various layers ulitized in construction of a single nozzle 1310. The bottom layer 1330 can be formed by back etching a silicon wafer which has a boron dope epitaxial layer as the etch stop. The boron dope layer 1330 can be further individually masked and etched so as to form nozzle rim 1331 and the nozzle ejection port 1312. Next, a silicon layer 1332 is formed. The silicon layer 1332 can be formed as part of the original wafer having the buried boron doped layer 1330. The nozzle chamber proper can be formed substantially from high density low pressure plasma etching of the silicon layer 1332 so as to produce substantially vertical side walls thereby forming the nozzle chamber. On top of the silicon layer 1332 is formed a glass layered 1333 which can include the drive and control circuitry required for driving an array of nozzles 1310. The drive and control circuitry can comprise standard two level metal CMOS circuitry intra-connected to form the copper coil circuit by means of vias though upper layers (not shown). Next, a nitride passivation layer 1334 is provided so as to passivate any lower glass layers, e.g. 1333, from sacrificial etches should a sacrificial etching be utilized in the formation of portions of the nozzle. On top of the nitride layer 1334 is formed a first nickel-ferrous layer 1336 followed by a copper layer 1337 and a further nickel-ferrous layer 1338 which can be formed via a dual damascene process. On top of the layer 1338 is formed the final nitride spring layer 1340 with the springs being formed by means of semiconductor treatment of the nitride layer 1340 so as to release the springs in tension so as to thereby cause a slight rating of the plunger 1314. A number of techniques not disclosed in Fig. 228 can be utilized in the construction of various portions of the arrangement 1310. For example, the nozzle chamber can be formed by utilizing the aforementioned plasma etch and then subsequently filling the nozzle chamber with sacrificial material such as glass so as to provide a support for the plunger 1314 with the plunger 1314 being subsequently released via sacrificial etching of the sacrificial layers.

[0080] Further, the tapered end portions of the nickel-ferrous material can be formed so that the utilisation of a half-tone mask having an intensity pattern corresponding to the desired bottom tapered profile of plunger 1314. The half-tone mask can be utilized to half-tone a resist so that the shape is transferred to the resist and subsequently to a lower layer, such as sacrificial glass on top of which is laid the nickel-ferrous material which can be finally planarised utilizing chemical mechanical planarization techniques.

[0081] One form of detailed manufacturing process which can be used to fabricate monolithic ink jet print heads operating in accordance with the principles taught by the present embodiment can proceed utilizing the following steps:

1. Using a double sided polished wafer deposit 3 microns of epitaxial silicon heavily doped with boron.
2. Deposit 10 microns of epitaxial silicon, either p-type or n-type, depending upon the CMOS process used.
3. Complete drive transistors, data distribution, and timing circuits using a 0.5 micron, one poly, 2 metal CMOS process. This step is shown in Fig. 45. For clarity, these diagrams may not be to scale, and may not represent a cross section though any single plane of the nozzle. Fig. 44 is a key to representations of various materials in these manufacturing diagrams, and those of other cross referenced ink jet configurations.
4. Etch the CMOS oxide layers down to silicon or aluminum using Mask 1. This mask defines the nozzle chamber and the edges of the print heads chips.
5. Plasma etch the silicon down to the boron doped buried layer, using oxide from step 4 as a mask. This etch does not substantially etch the aluminum. This step is shown in Fig. 46.
6. Deposit 0.5 microns of silicon nitride (Si_3N_4).
7. Deposit 12 microns of sacrificial material.
8. Planarize down to nitride using CMP. This fills the nozzle chamber level to the chip surface. This step is shown in Fig. 47.
9. Etch nitride and CMOS oxide layers down to second level metal using Mask 2. This mask defines the vias for the contacts from the second level metal electrodes to the two halves of the split fixed magnetic pole. This step is shown in Fig. 48.
10. Deposit a seed layer of cobalt nickel iron alloy. CoNiFe is chosen due to a high saturation flux density of 2 Tesla, and a low coercivity. [Osaka, Tetsuya et al, A soft magnetic CoNiFe film with high saturation magnetic flux density, Nature 392, 796-798 (1998)].
11. Spin on 5 microns of resist, expose with Mask 3, and develop. This mask defines the lowest layer of the split fixed magnetic pole, and the thinnest rim of the magnetic plunger. The resist acts as an electroplating mold. This step is shown in Fig. 49.
12. Eletroplate 4 microns of CoNiFe. This step is shown in Fig. 50.
13. Deposit 0.1 microns of silicon nitride (Si_3N_4).
14. Etch the nitride layer using Mask 4. This mask defines the contact vias from each end of the solenoid coil to the two halves of the split fixed magnetic pole.
15. Deposit a seed layer of copper.
16. Spin on 5 microns of resist, expose with Mask 5, and develop. This mask defines the solenoid spiral coil and the spring posts, for which the resist acts as an electroplating mold. This step is shown in Fig. 51.
17. Electroplate 4 microns of copper. Copper is used for its low resistivity (which results in higher efficiency) and its high electromigration resistance, which increases reliability at high current densities.
18. Strip the resist and etch the exposed copper seed layer. This step is shown in Fig. 52.
19. Wafer probe. All electrical connections are complete at this point, bond pads are accessible, and the chips are not yet separated.
20. Deposit 0.1 microns of silicon nitride. This layer of nitride provides corrosion protection and electrical insulation to the copper coil.
21. Etch the nitride layer using Mask 6. This mask defines the regions of continuity between the lower and the

middle layers of CoNiFe.

22. Spin on 4.5 microns of resist, expose with Mask 6, and develop. This mask defines the middle layer of the split fixed magnetic pole, and the middle rim of the magnetic plunger. The resist forms an electroplating mold for these parts. This step is shown in Fig. 53.

23. Electroplate 4 microns of CoNiFe. The lowest layer of CoNiFe acts as the seed layer. This step is shown in Fig. 54.

24. Deposit a seed layer of CoNiFe.

25. Spin on 4.5 microns of resist, expose with Mask 7, and develop. This mask defines the highest layer of the split fixed magnetic pole and the roof of the magnetic plunger. The resist forms an electroplating mold for these parts. This step is shown in Fig. 55.

26. Electroplate 4 microns of CoNiFe. This step is shown in Fig. 56.

27. Deposit 1 micron of sacrificial material.

28. Etch the sacrificial material using Mask 8. This mask defines the contact points of the nitride springs to the split fixed magnetic poles and the magnetic plunger. This step is shown in Fig. 57.

29. Deposit 0.1 microns of low stress silicon nitride.

30. Deposit 0.1 microns of high stress silicon nitride. These two layers of nitride form a pre-stressed spring which lifts the magnetic plunger out of core space of the fixed magnetic pole.

31. Etch the two layers of nitride using Mask 9. This mask defines the nitride spring. This step is shown in Fig. 58.

32. Mount the wafer on a glass blank and back-etch the water using KOH with no mask. This etch thins the wafer and stops at the buried boron doped silicon layer. This step is shown in Fig. 59.

33. Plasma bock-etch the boron doped silicon layer to a depth of (approx.) 1 micron using Mask 10. This mask defines the nozzle rim. This step is shown in Fig. 60.

34. Plasma back-etch through the boron doped layer using Mask 11. This mask defines the nozzle, and the edge of the chips. At this stage, the chips are separate, but are still mounted on the glass blank. This step is shown in Fig. 61.

35. Detach the chips from the glass blank. Strip all adhesive, resist, sacrificial, and exposed seed layers. The nitride spring is released in this step, lifting the magnetic plunger out of the fixed magnetic pole by 3 microns. This step is shown in Fig. 62.

36. Mount the print heads in their packaging, which may be a molded plastic former incorporating ink channels which supply different colors of ink to the appropriate regions of the front surface of the wafer.

37. Connect the print heads to their interconnect systems.

38. Hydrophobize the front surface of the print heads.

39. Fill the completed print heads with ink and test them. A filled nozzle is shown in Fig. 63.

IJ USES

[0082] The presently disclosed ink jet printing technology is potentially suited to a wide range of printing system including: colour and monochrome office printers, short run digital printers, high speed digital printers, offset press supplemental printers, low cost scanning printers high speed pagewidth printers, notebook computers with inbuilt pagewidth printers, portable colour and monochrome printers, colour and monochrome copiers, colour and monochrome facsimile machines, combined printer, facsimile and copying machines, label printers, large format plotters, photograph copiers, printers for digital photographic "minilabs", video printers, PhotoCD printers, portable printers for PDAs, wallpaper printers, indoor sign printers, billboard printers, fabric printers, camera printers and fault tolerant commercial printer arrays.

Ink Jet Technologies

[0083] The embodiments of the invention use an ink jet printer type device. Of course many different devices could be used. However presently popular ink jet printing technologies are unlikely to be suitable.

[0084] The most significant problem with thermal inkjet is power consumption. This is approximately 100 times that required for high speed, and stems from the energy-inefficient means of drop ejection. This involves the rapid boiling of water to produce a vapor bubble which expels the ink. Water has a very high heat capacity, and must be superheated in thermal inkjet applications. This leads to an efficiency of around 0.02%, from electricity input to drop momentum (and increased surface area) out.

[0085] The most significant problem with piezoelectric inkjet is size and cost. Piezoelectric crystals have a very small deflection at reasonable drive voltages, and therefore require a large area for each nozzle. Also, each piezoelectric actuator must be connected to its drive circuit on a separate substrate. This is not a significant problem at the current limit of around 300 nozzles per print head, but is a major impediment to the fabrication of pagewide print beads with

19,200 nozzles.

[0086] Ideally, the inktet technologies used meet the stringent requirements of in-camera digital color printing and other high quality, high speed, low cost printing applications. To meet the requirements of digital photography, new inkjet technologies have been created. The target features include:

low power (less than 10 Watts)
high resolution capability (1,600 dpi or more)
photographic quality output
low manufacturing cost
small size (pagewidth times minimum cross section)
high speed (<2 seconds per page).

[0087] All of these features can be met or exceeded by the inkjet systems described below with differing levels of difficulty. 45 different inkjet technologies have been developed by the Assignee to give a wide range of choices for high volume manufacture. These technologies form part of separate applications assigned to the present Assignee as set out in the table below.

[0088] The inkjet designs shown here at suitable for a wide range of digital printing systems, from battery powered one-time use digital cameras, through to desktop and network printers, and through to commercial printing systems

[0089] For ease of manufacture using standard process equipment, the print head is designed to be a monolithic 0.5 micron CMOS chip with MEMS post processing. For color photographic applications, the print head is 100 mm long, with a width which depends upon the inkjet type. The smallest print head designed is IJ38, which is 0.35 mm wide, giving a chip area of 35 square mm. The print heads each contain 19,200 nozzles plus data and control circuitry.

[0090] Ink is supplied to the back of the print head by injection molded plastic ink channels. The molding requires 50 micron features, which can be created using a lithographically micromachined insert in a standard injection molding tool. Ink flows through holes etched through the wafer to the nozzle chambers fabricated on the front surface of the wafer. The print head is connected to the camera circuitry by tape automated bonding.

Cross-Referenced Applications

[0091] The following table is a guide to cross-referenced patent applications filed concurrently herewith and discussed hereinafter with the reference being utilized in subsequent tables what referring to a particular case:

Docket No.	Reference	Title
IJ01US	IJ01	Radiant Plunger Ink Jet Printer
IJ02US	IJ02	Electrostatic Ink Jet Printer
IJ03US	IJ03	Planar Thermoelastic Bend Actuator Ink Jet
IJ04US	IJ04	Stacked Electrostatic Ink Jet Printer
IJ05US	IJ05	Reverse Spring Lever Ink Jet Printer
IJ06US	IJ06	Paddle Type Ink Jet Printer
IJ07US	IJ07	Permanent Magnet Electromagnetic Ink Jet Printer
IJ08US	IJ08	Planar Swing Grill Electromagnetic Ink Jet Printer
IJ09US	IJ09	Pump Action Refill Ink Jet Printer
IJ10US	IJ10	Pulsed Magnetic Field Ink Jet Printer
IJ11US	IJ11	Two Plate Reverse Firing Electromagnetic Ink Jet Printer
IJ12US	IJ12	Linear Stepper Actuator Ink Jet Printer
IJ13US	IJ13	Gear Driven Shutter Ink Jet Printer
IJ14US	IJ14	Tapered Magnetic Pole Electromagnctic Ink Jet Printer
IJ15US	IJ15	Linear Spring Electromagnetic Grill Ink Jet Printer
IJ16US	IJ16	Lorenz Diaphragm Electromagnetic Ink Jet Printer
IJ17US	IJ17	PTFE Surface Shooting Shuttered Oscillating Pressure Ink Jet printer

(continued)

Docket No.	Reference	Title
IJ18US	IJ18	Buckle Grip Oscillating Pressure Ink Jet Printer
IJ19US	IJ19	Shutter Based Ink Jet Printer
IJ20US	IJ20	Curling Calyx Thermoelastic Ink Jet Printer
IJ21US	IJ21	Thermal Actuated Ink Jet Printer
IJ22US	IJ22	Iris Motion Ink Jet Printer
IJ23US	IJ23	Direct Firing Thermal Bend Actuator Ink Jet Printer
IJ24US	IJ24	Conductive PTFE Ben Activator Vented Ink Jet Printer
IJ25US	IJ25	Magnetostrictive Ink Jet Printer
IJ26US	IJ26	Shape Memory Alloy Ink Jet Printer
IJ27US	IJ27	Buckle Plate Ink Jet Printer
IJ28US	IJ28	Thermal Elastic Rotary Impeller Ink Jet Printer
IJ29US	IJ29	Thermoelastic Bend Actuator Ink Jet printer
IJ30US	IJ30	Thermoelastic Bend Actuator Using PTFE and Corrugated Copper Ink Jet Printer
IJ31US	IJ31	Bend Actuator Direct Ink Supply Ink Jet Printer
IJ32US	IJ32	A High Young's Modulus Thermoelastic Ink Jet Printer
IJ33US	IJ33	Thermally actuated slotted chamber wall ink jet printer
IJ34US	IJ34	Ink Jet Printer having a thermal actuator comprising an external coiled spring
IJ35US	IJ35	Trough Container Ink Jet Printer
IJ36US	IJ36	Dual Chamber Single Vertical Actuator Ink Jet
IJ37US	IJ37	Dual Nozzle Single Horizontal Fulcrum Actuator Ink Jet
IJ38US	IJ38	Dual Nozzle Single Horizontal Aduator Ink Jet
IJ39US	IJ39	A single bend actuator cupped paddle ink jet printing device
IJ40US	IJ40	A thermally actuated ink jet printer having a series of thermal actuator units
IJ41US	IJ41	A thermally actuated ink jet printer including a tapered heater element
IJ42US	IJ42	Radial Back-Curling Thermoelastic Ink Jet
IJ43US	IJ43	Inverted Radial Back-Curling Thermoelastic Ink Jet
IJ44US	IJ44	Surface bend actuator vented ink supply ink jet printer
IJ45US	IJ45	Coil Actuated Magnetic Plate Ink Jet Printer

Tables of Drop-on-Demand Inkjets

[0092] Eleven important characteristics of the fundamental operation of individual inkjet nozzles have been identified. These characteristies are largely orthogonal, and so can be elucidated as an eleven dimensional matrix. Most of the eleven axes of this matrix include entries developed by the present assignee.

[0093] The following tables form the axes of an eleven dimensional table of inkjet types.

Actuator mechanism (18 types)
Basic operation mode (7 types)
Auxiliary mechanism (8 types)
Actuator amplification or modification method (17 types)
Actuator motion (19 types)
Nozzle refill method (4 types)

Method of restricting back-flow through inlet (10 types)
Nozzle clearing method (9 types)
Nozzle plate construction (9 types)
Drop ejection direction (5 types)
Ink type (7 types)

[0094] The complete eleven dimensional table represented by these axes contains 36.9 billion possible configurations of inkjet nozzle. While not all of the possible combinations result in a viable inkjet technology, many million configurations are viable. It is clearly impractical to elucidate all of the possible configurations. Instead, certain inkjet types have been investigated in detail. These are designated IJ01 to IJ45 above.

[0095] Other inkjet configurations can readily be derived from these 45 examples by substituting alternative configurations along one or more of the 11 axes. Most of the IJ01 to IJ45 examples can be made into inkjet print heads with characteristics superior to any currently available inkjet technology.

[0096] Where there are prior art examples known to the inventor, one or more of these examples are listed in the examples column of the tables below. The IJ01 to IJ45 series are also listed in the examples column. In some cases, a printer may be listed more than once in a table, where it shares characteristics with more than one entry.

[0097] Suitable applications include: Home printers, Office network printers, Short run digital printers, Commercial print systems, Fabric printers, Pocket Printers, Internet WWW printers, Video printers, Medical imaging, Wide format printers, Notebook PC printers, Fax machines, Industrial printing systems, Photocopiers, Photographic minilabs etc.

[0098] The information associated with the aforementioned 11 dimensional matrix are set out in the following tables.

Actuator mechanism (applied only to selected ink drops)

Actuator Mechanism	Description	Advantages	Disadvantages	Examples
Thermal bubble	An electrothermal heater heats the ink to above boiling point, transferring significant heat to the aqueous ink. A bubble nucleates and quickly forms, expelling the ink. The efficiency of the process is low, with typically less than 0.05% of the electrical energy being transformed into kinetic energy of the drop.	♦ Large force generated ♦ Simple construction ♦ No moving parts ♦ Fast operation ♦ Small chip area required for actuator	♦ High power ♦ Ink carrier limited to water ♦ Low efficiency ♦ High temperatures required ♦ High mechanical stress ♦ Unusual materials required ♦ Large drive transistors ♦ Cavitation causes actuator failure ♦ Kogation reduces bubble formation ♦ Large print heads are difficult to fabricate	♦ Canon Bubblejet 1979 Endo et al GB patent 2,007,162 ♦ Xerox heater-in-pit 1990 Hawkins et al USP 4,899,181 ♦ Hewlett-Packard TIJ 1982 Vaught et al USP 4,490,728
Piezoelectric	A piezoelectric crystal such as lead lanthanum zirconate (PZT) is electrically activated, and either expands, shears, or bends to apply pressure to the ink, ejecting drops.	♦ Low power consumption ♦ Many ink types can be used ♦ Fast operation ♦ High efficiency	♦ Very large area required for actuator ♦ Difficult to integrate with electronics ♦ High voltage drive transistors required ♦ Full pagewidth print heads impractical due to actuator size ♦ Requires electrical poling in high field strengths during manufacture	♦ Kyser et al USP 3,946,398 ♦ Zoltan USP 3,683,212 ♦ 1973 Stemme USP 3,747,120 ♦ Epson Stylus ♦ Tektronix ♦ IJ04

Electro-strictive	An electric field is used to activate electrostriction in relaxor materials such as lead lanthanum zirconate titanate (PLZT) or lead magnesium niobate (PMN).	♦ Low power consumption ♦ Many ink types can be used ♦ Low thermal expansion ♦ Electric field strength required (approx. 3.5 V/μm) can be generated without difficulty ♦ Does not require electrical poling	♦ Low maximum strain (approx. 0.01%) ♦ Large area required for actuator due to low strain ♦ Response speed is marginal (~ 10 μs) ♦ High voltage drive transistors required ♦ Full pagewidth print heads impractical due to actuator size	♦ Seiko Epson, Usui et all JP 253401/96 ♦ IJ04
Ferroelectric	An electric field is used to induce a phase transition between the antiferroelectric (AFE) and ferroelectric (FE) phase. Perovskite materials such as tin modified lead lanthanum zirconate titanate (PLZSnT) exhibit large strains of up to 1% associated with the AFE to FE phase transition.	♦ Low power consumption ♦ Many ink types can be used ♦ Fast operation (< 1 μs) ♦ Relatively high longitudinal strain ♦ High efficiency ♦ Electric field strength of around 3 V/μm can be readily provided	♦ Difficult to integrate with electronics ♦ Unusual materials such as PLZSnT are required ♦ Actuators require a large area	♦ IJ04

Electrostatic plates	Conductive plates are separated by a compressible or fluid dielectric (usually air). Upon application of a voltage, the plates attract each other and displace ink, causing drop ejection. The conductive plates may be in a comb or honeycomb structure, or stacked to increase the surface area and therefore the force.	♦ Low power consumption ♦ Many ink types can be used ♦ Fast operation	♦ Difficult to operate electrostatic devices in an aqueous environment ♦ The electrostatic actuator will normally need to be separated from the ink ♦ Very large area required to achieve high forces ♦ High voltage drive transistors may be required ♦ Full pagewidth print heads are not competitive due to actuator size	♦ IJ02, IJ04
Electrostatic pull on ink	A strong electric field is applied to the ink, whereupon electrostatic attraction accelerates the ink towards the print medium.	♦ Low current consumption ♦ Low temperature	♦ High voltage required ♦ May be damaged by sparks due to air breakdown ♦ Required field strength increases as the drop size decreases ♦ High voltage drive transistors required ♦ Electrostatic field attracts dust	♦ 1989 Saito et al, USP 4,799,068 ♦ 1989 Miura et al, USP 4,810,954 ♦ Tone-jet

Permanent magnet electro-magnetic	An electromagnet directly attracts a permanent magnet, displacing ink and causing drop ejection. Rare earth magnets with a field strength around 1 Tesla can be used. Examples are: Samarium Cobalt (SaCo) and magnetic materials in the neodymium iron boron family (NdFeB, NdDyFeBNb, NdDyFeB, etc)	♦ Low power consumption ♦ Many ink types can be used ♦ Fast operation ♦ High efficiency ♦ Easy extension from single nozzles to pagewidth print heads	♦ Complex fabrication ♦ Permanent magnetic material such as Neodymium Iron Boron (NdFeB) required. ♦ High local currents required ♦ Copper metalization should be used for long electromigration lifetime and low resistivity ♦ Pigmented inks are usually infeasible ♦ Operating temperature limited to the [illegible] (around 540 K)	♦ IJ07, IJ10
Soft magnetic core electro-magnetic	A solenoid induced a magnetic field in a soft magnetic core or yoke fabricated from a ferrous material such as electroplated iron alloys such as CoNiFe [1], CoFe, or NiFe alloys. Typically, the soft magnetic material is in two parts, which are normally held apart by a spring. When the solenoid is actuated, the two parts attract, displacing the ink.	♦ Low power consumption ♦ Many ink types can be used ♦ Fast operation ♦ High efficiency ♦ Easy extension from single nozzles to pagewidth print heads	♦ Complex fabrication ♦ Materials not usually present in a CMOS fab such as NiFe, CoNiFe, or CoFe are required ♦ High local currents required ♦ Copper metalization should be used for long electromigration lifetime and low resistivity ♦ Electroplating is required ♦ High saturation flux density is required (2.0-2.1 T is achievable with CoNiFe [1])	♦ IJ01, IJ05, IJ08, IJ10 ♦ IJ12, IJ14, IJ15, IJ17

Magnetic Lorenz force	The Lorenz force acting on a current carrying wire in a magnetic field is utilized. This allows the magnetic field to be supplied externally to the print head, for example with rare earth permanent magnets. Only the current carrying wire need be fabricated on the print-head, simplifying materials requirements.	♦ Low power consumption ♦ Many ink types can be used ♦ Fast operation ♦ High efficiency ♦ Easy extension from single nozzles to pagewidth print heads	♦ Force acts as a twisting motion ♦ Typically, only a quarter of the solenoid length provides force in a useful direction ♦ High local currents required ♦ Copper metalization should be used for long electromigration lifetime and low resistivity ♦ Pigmented inks are usually infeasible	♦ IJ06, IJ11, IJ13, IJ16
Magneto-striction	The actuator uses the giant magnetostrictive effect of materials such as Terfenol-D (an alloy of terbium, dysprosium and iron developed at the Naval Ordnance Laboratory, hence Ter-Fe-NOL). For best efficiency, the actuator should be pre-stressed to approx. 8 MPa.	♦ Many ink types can be used ♦ Fast operation ♦ Easy extension from single nozzles to pagewidth print heads ♦ High force is available	♦ Force acts as a twisting motion ♦ Unusual materials such as Terfenol-D are required ♦ High local currents required ♦ Copper metalization should be used for long electromigration lifetime and low resistivity ♦ Pre-stressing may be required	♦ Fischenbeck, USP 4,032,929 ♦ IJ25

Surface tension reduction	Ink under positive pressure is held in a nozzle by surface tension. The surface tension of the ink is reduced below the bubble threshold, causing the ink to egress from the nozzle.	♦ Low power consumption ♦ Simple construction ♦ No unusual materials required in fabrication ♦ High efficiency ♦ Easy extension from single nozzles to pagewidth print heads	♦ Requires supplementary force to effect drop separation ♦ Requires special ink surfactants ♦ Speed may be limited by surfactant properties	♦ Silverbrook, EP 0771 658 A2 and related patent applications
Viscosity reduction	The ink viscosity is locally reduced to select which drops are to be ejected. A viscosity reduction can be achieved electrothermally with most inks, but special inks can be engineered for a 100:1 viscosity reduction.	♦ Simple construction ♦ No unusual materials required in fabrication ♦ Easy extension from single nozzles to pagewidth print heads	♦ Requires supplementary force to effect drop separation. ♦ Requires special ink viscosity properties ♦ High speed is difficult to achieve ♦ Requires oscillating ink pressure ♦ A high temperature difference (typically 80 degrees) is required	♦ Silverbrook, EP 0771 658 A2 and related patent applications
Acoustic	An acoustic wave is generated and focussed upon the drop ejection region.	♦ Can operate without a nozzle plate	♦ Complex drive circuitry ♦ Complex fabrication ♦ Low efficiency ♦ Poor control of drop position ♦ Poor control of drop volume	♦ 1993 Hadimioglu et al, EUP 550,192 ♦ 1993 Elrod et al, EUP 572,220

Thermoelastic bend actuator	An actuator which relies upon differential thermal expansion upon Joule heating is used.	♦ Low power consumption ♦ Many ink types can be used ♦ Simple planar fabrication ♦ Small chip area required for each actuator ♦ Fast operation ♦ High efficiency ♦ CMOS compatible voltages and currents ♦ Standard MEMS processes can be used ♦ Easy extension from single nozzles to pagewidth print heads	♦ Efficient aqueous operation requires a thermal insulator on the hot side ♦ Corrosion prevention can be difficult ♦ Pigmented inks may be infeasible, as pigment particles may jam the bend actuator	♦ IJ03, IJ09, IJ17, IJ18 ♦ IJ19, IJ20, IJ21, IJ22 ♦ IJ23, IJ24, IJ27, IJ28 ♦ IJ29, IJ30, IJ31, IJ32 ♦ IJ33, IJ34, IJ35, IJ36 ♦ IJ37, IJ38 ,IJ39, IJ40 ♦ IJ41

High CTE thermoelastic actuator	A material with a very high coefficient of thermal expansion (CTE) such as polytetrafluoroethylene (PTFE) is used. As high CTE materials are usually non-conductive, a heater fabricated from a conductive material is incorporated. A 50 μm long PTFE bend actuator with polysilicon heater and 15 mW power input can provide 180 μN force and 10 μm deflection. Actuator motions include: 1) Bend 2) Push 3) Buckle 4) Rotate	♦ High force can be generated ♦ PTFE is a candidate for low dielectric constant insulation in ULSI ♦ Very low power consumption ♦ Many ink types can be used ♦ Simple planar fabrication ♦ Small chip area required for each actuator ♦ Fast operation ♦ High efficiency ♦ CMOS compatible voltages and currents ♦ Easy extension from single nozzles to pagewidth print heads	♦ Requires special material (e.g. PTFE) ♦ Requires a PTFE deposition process, which is not yet standard in ULSI fabs ♦ PTFE deposition cannot be followed with high temperature (above 350 °C) processing ♦ Pigmented inks may be infeasible, as pigment particles may jam the bend actuator	♦ IJ09, IJ17, IJ18, IJ20 ♦ IJ21, IJ22, IJ23, IJ24 ♦ IJ27, IJ28, IJ29, IJ30 ♦ IJ31, IJ42, IJ43, IJ44

Conductive polymer thermoelastic actuator	A polymer with a high coefficient of thermal expansion (such as PTFE) is doped with conducting substances to increase its conductivity to about 3 orders of magnitude below that of copper. The conducting polymer expands when resistively heated. Examples of conducting dopants include: 1) Carbon nanotubes 2) Metal fibers 3) Conductive polymers such as doped polythiophene 4) Carbon granules	♦ High force can be generated ♦ Very low power consumption ♦ Many ink types can be used ♦ Simple planar fabrication ♦ Small chip area required for each actuator ♦ Fast operation ♦ High efficiency ♦ CMOS compatible voltages and currents ♦ Easy extension from single nozzles to pagewidth print heads	♦ Requires special materials development (High CTE conductive polymer) ♦ Requires a PTFE deposition process, which is not yet standard in ULSI fabs ♦ PTFE deposition cannot be followed with high temperature (above 350 °C) processing ♦ Evaporation and CVD deposition techniques cannot be used ♦ Pigmented inks may be infeasible, as pigment particles may jam the bend actuator	♦ IJ24
Shape memory alloy	A shape memory alloy such as TiNi (also known as Nitinol - Nickel Titanium alloy developed at the Naval Ordnance Laboratory) is thermally switched between its weak martensitic state and its high stiffness austenic state. The shape of the actuator in its martensitic state is deformed relative to the austenic shape. The shape change causes ejection of a drop.	♦ High force is available (stresses of hundreds of MPa) ♦ Large strain is available (more than 3%) ♦ High corrosion resistance ♦ Simple construction ♦ Easy extension from single nozzles to pagewidth print heads ♦ Low voltage operation	♦ Fatigue limits maximum number of cycles ♦ Low strain (1%) is required to extend fatigue resistance ♦ Cycle rate limited by heat removal ♦ Requires unusual materials (TiNi) ♦ The latent heat of transformation must be provided ♦ High current operation ♦ Requires pre-stressing to distort the martensitic state	♦ IJ26

Linear Magnetic Actuator	Linear magnetic actuators include the Linear Induction Actuator (LIA), Linear Permanent Magnet Synchronous Actuator (LPMSA), Linear Reluctance Synchronous Actuator (LRSA), Linear Switched Reluctance Actuator (LSRA), and the Linear Stepper Actuator (LSA).	♦ Linear Magnetic actuators can be constructed with high thrust, long travel, and high efficiency using planar semiconductor fabrication techniques ♦ Long actuator travel is available ♦ Medium force is available ♦ Low voltage operation	♦ Requires unusual semiconductor materials such as soft magnetic alloys (e.g. CoNiFe [1]) ♦ Some varieties also require permanent magnetic materials such as Neodymium iron boron (NdFeB) ♦ Requires complex multi-phase drive circuitry ♦ High current operation	♦ IJ12

Basic operation mode

Operational mode	Description	Advantages	Disadvantages	Examples
Actuator directly pushes ink	This is the simplest mode of operation: the actuator directly supplies sufficient kinetic energy to expel the drop. The drop must have a sufficient velocity to overcome the surface tension.	♦ Simple operation. ♦ No external fields required ♦ Satellite drops can be avoided if drop velocity is less than 4 m/s ♦ Can be efficient, depending upon the actuator used	♦ Drop repetition rate is usually limited to less than 10 KHz. However, this is not fundamental to the method, but is related to the refill method normally used ♦ All of the drop kinetic energy must be provided by the actuator ♦ Satellite drops usually form if drop velocity is greater than 4.5 m/s	♦ Thermal inkjet ♦ Piezoelectric inkjet ♦ IJ01, IJ02, IJ03, IJ04 ♦ IJ05, IJ06, IJ07, IJ09 ♦ IJ11, IJ12, IJ14, IJ16 ♦ IJ20, IJ22, IJ23, IJ24 ♦ IJ25, IJ26, IJ27, IJ28 ♦ IJ29, IJ30, IJ31, IJ32 ♦ IJ33, IJ34, IJ35, IJ36 ♦ IJ37, IJ38, IJ39, IJ40 ♦ IJ41, IJ42, IJ43, IJ44

Proximity	The drops to be printed are selected by some manner (e.g. thermally induced surface tension reduction of pressurized ink). Selected drops are separated from the ink in the nozzle by contact with the print medium or a transfer roller.	♦ Very simple print head fabrication can be used ♦ The drop selection means does not need to provide the energy required to separate the drop from the nozzle	♦ Requires close proximity between the print head and the print media or transfer roller ♦ May require two print heads printing alternate rows of the image ♦ Monolithic color print heads are difficult	♦ Silverbrook, EP 0771 658 A2 and related patent applications
Electrostatic pull on ink	The drops to be printed are selected by some manner (e.g. thermally induced surface tension reduction of pressurized ink). Selected drops are separated from the ink in the nozzle by a strong electric field.	♦ Very simple print head fabrication can be used ♦ The drop selection means does not need to provide the energy required to separate the drop from the nozzle	♦ Requires very high electrostatic field ♦ Electrostatic field for small nozzle sizes is above air breakdown ♦ Electrostatic field may attract dust	♦ Silverbrook, EP 0771 658 A2 and related patent applications ♦ Tone-Jet
Magnetic pull on ink	The drops to be printed are selected by some manner (e.g. thermally induced surface tension reduction of pressurized ink). Selected drops are separated from the ink in the nozzle by a strong magnetic field acting on the magnetic ink.	♦ Very simple print head fabrication can be used ♦ The drop selection means does not need to provide the energy required to separate the drop from the nozzle	♦ Requires magnetic ink ♦ Ink colors other than black are difficult ♦ Requires very high magnetic fields	♦ Silverbrook, EP 0771 658 A2 and related patent applications

Shutter	The actuator moves a shutter to block ink flow to the nozzle. The ink pressure is pulsed at a multiple of the drop ejection frequency.	♦ High speed (>50 KHz) operation can be achieved due to reduced refill time ♦ Drop timing can be very accurate ♦ The actuator energy can be very low	♦ Moving parts are required ♦ Requires ink pressure modulator ♦ Friction and wear must be considered ♦ Stiction is possible	♦ IJ13, IJ17, IJ21
Shuttered grill	The actuator moves a shutter to block ink flow through a grill to the nozzle. The shutter movement need only be equal to the width of the grill holes.	♦ Actuators with small travel can be used ♦ Actuators with small force can be used ♦ High speed (>50 KHz) operation can be achieved	♦ Moving parts are required ♦ Requires ink pressure modulator ♦ Friction and wear must be considered ♦ Stiction is possible	♦ IJ08, IJ15, IJ18, IJ19
Pulsed magnetic pull on ink pusher	A pulsed magnetic field attracts an 'ink pusher' at the drop ejection frequency. An actuator controls a catch, which prevents the ink pusher from moving when a drop is not to be ejected.	♦ Extremely low energy operation is possible ♦ No heat dissipation problems	♦ Requires an external pulsed magnetic field ♦ Requires special materials for both the actuator and the ink pusher ♦ Complex construction	♦ IJ10

Auxiliary mechanism (applied to all nozzles)

Auxiliary Mechanism	Description	Advantages	Disadvantages	Examples

None	The actuator directly fires the ink drop, and there is no external field or other mechanism required.	♦ Simplicity of construction ♦ Simplicity of operation ♦ Small physical size	♦ Drop ejection energy must be supplied by individual nozzle actuator	♦ Most inkjets, including piezoelectric and thermal bubble. ♦ IJ01- IJ07, IJ09, IJ11 ♦ IJ12, IJ14, IJ20, IJ22 ♦ IJ23-IJ45
Oscillating ink pressure (including acoustic stimulation)	The ink pressure oscillates, providing much of the drop ejection energy. The actuator selects which drops are to be fired by selectively blocking or enabling nozzles. The ink pressure oscillation may be achieved by vibrating the print head, or preferably by an actuator in the ink supply.	♦ Oscillating ink pressure can provide a refill pulse, allowing higher operating speed ♦ The actuators may operate with much lower energy ♦ Acoustic lenses can be used to focus the sound on the nozzles	♦ Requires external ink pressure oscillator ♦ Ink pressure phase and amplitude must be carefully controlled ♦ Acoustic reflections in the ink chamber must be designed for	♦ Silverbrook, EP 0771 658 A2 and related patent applications ♦ IJ08, IJ13, IJ15, IJ17 ♦ IJ18, IJ19, IJ21
Media proximity	The print head is placed in close proximity to the print medium. Selected drops protrude from the print head further than unselected drops, and contact the print medium. The drop soaks into the medium fast enough to cause drop separation.	♦ Low power ♦ High accuracy ♦ Simple print head construction	♦ Precision assembly required ♦ Paper fibers may cause problems ♦ Cannot print on rough substrates	♦ Silverbrook, EP 0771 658 A2 and related patent applications

Transfer roller	Drops are printed to a transfer roller instead of straight to the print medium. A transfer roller can also be used for proximity drop separation.	♦ High accuracy ♦ Wide range of print substrates can be used ♦ Ink can be dried on the transfer roller	♦ Bulky ♦ Expensive ♦ Complex construction	♦ Silverbrook, EP 0771 658 A2 and related patent applications ♦ Tektronix hot melt piezoelectric inkjet ♦ Any of the IJ series
Electrostatic	An electric field is used to accelerate selected drops towards the print medium.	♦ Low power ♦ Simple print head construction	♦ Field strength required for separation of small drops is near or above air breakdown	♦ Silverbrook, EP 0771 658 A2 and related patent applications ♦ Tone-Jet
Direct magnetic field	A magnetic field is used to accelerate selected drops of magnetic ink towards the print medium.	♦ Low power ♦ Simple print head construction	♦ Requires magnetic ink ♦ Requires strong magnetic field	♦ Silverbrook, EP 0771 658 A2 and related patent applications
Cross magnetic field	The print head is placed in a constant magnetic field. The Lorenz force in a current carrying wire is used to move the actuator.	♦ Does not require magnetic materials to be integrated in the print head manufacturing process	♦ Requires external magnet ♦ Current densities may be high, resulting in electromigration problems	♦ IJ06, IJ16
Pulsed magnetic field	A pulsed magnetic field is used to cyclically attract a paddle, which pushes on the ink. A small actuator moves a catch, which selectively prevents the paddle from moving.	♦ Very low power operation is possible ♦ Small print head size	♦ Complex print head construction ♦ Magnetic materials required in print head	♦ IJ10

<u>Actuator amplification or modification method</u>

Actuator amplification	Description	Advantages	Disadvantages	Examples
None	No actuator mechanical amplification is used. The actuator directly drives the drop ejection process.	♦ Operational simplicity	♦ Many actuator mechanisms have insufficient travel, or insufficient force, to efficiently drive the drop ejection process	♦ Thermal Bubble Inkjet ♦ IJ01, IJ02, IJ06, IJ07 ♦ IJ16, IJ25, IJ26
Differential expansion bend actuator	An actuator material expands more on one side than on the other. The expansion may be thermal, piezoelectric, magnetostrictive, or other mechanism.	♦ Provides greater travel in a reduced print head area ♦ The bend actuator converts a high force low travel actuator mechanism to high travel, lower force mechanism.	♦ High stresses are involved ♦ Care must be taken that the materials do not delaminate ♦ Residual bend resulting from high temperature or high stress during formation	♦ Piezoelectric ♦ IJ03, IJ09, IJ17-IJ24 ♦ IJ27, IJ29-IJ39, IJ42, ♦ IJ43, IJ44
Transient bend actuator	A trilayer bend actuator where the two outside layers are identical. This cancels bend due to ambient temperature and residual stress. The actuator only responds to transient heating of one side or the other.	♦ Very good temperature stability ♦ High speed, as a new drop can be fired before heat dissipates ♦ Cancels residual stress of formation	♦ High stresses are involved ♦ Care must be taken that the materials do not delaminate	♦ IJ40, IJ41
Actuator stack	A series of thin actuators are stacked. This can be appropriate where actuators require high electric field strength, such as electrostatic and piezoelectric actuators.	♦ Increased travel ♦ Reduced drive voltage	♦ Increased fabrication complexity ♦ Increased possibility of short circuits due to pinholes	♦ Some piezoelectric ink jets ♦ IJ04

Multiple actuators	Multiple smaller actuators are used simultaneously to move the ink. Each actuator need provide only a portion of the force required.	♦ Increases the force available from an actuator ♦ Multiple actuators can be positioned to control ink flow accurately	♦ Actuator forces may not add linearly, reducing efficiency	♦ IJ12, IJ13, IJ18, IJ20 ♦ IJ22, IJ28, IJ42, IJ43
Linear Spring	A linear spring is used to transform a motion with small travel and high force into a longer travel, lower force motion.	♦ Matches low travel actuator with higher travel requirements ♦ Non-contact method of motion transformation	♦ Requires print head area for the spring	♦ IJ15
Reverse spring	The actuator loads a spring. When the actuator is turned off, the spring releases. This can reverse the force/distance curve of the actuator to make it compatible with the force/time requirements of the drop ejection.	♦ Better coupling to the ink	♦ Fabrication complexity ♦ High stress in the spring	♦ IJ05, IJ11
Coiled actuator	A bend actuator is coiled to provide greater travel in a reduced chip area.	♦ Increases travel ♦ Reduces chip area ♦ Planar implementations are relatively easy to fabricate.	♦ Generally restricted to planar implementations due to extreme fabrication difficulty in other orientations.	♦ IJ17, IJ21, IJ34, IJ35

Flexure bend actuator	A bend actuator has a small region near the fixture point, which flexes much more readily than the remainder of the actuator. The actuator flexing is effectively converted from an even coiling to an angular bend, resulting in greater travel of the actuator tip.	♦ Simple means of increasing travel of a bend actuator	♦ Care must be taken not to exceed the elastic limit in the flexure area ♦ Stress distribution is very uneven ♦ Difficult to accurately model with finite element analysis	♦ IJ10, IJ19, IJ33
Gears	Gears can be used to increase travel at the expense of duration. Circular gears, rack and pinion, ratchets, and other gearing methods can be used.	♦ Low force, low travel actuators can be used ♦ Can be fabricated using standard surface MEMS processes	♦ Moving parts are required ♦ Several actuator cycles are required ♦ More complex drive electronics ♦ Complex construction ♦ Friction, friction, and wear are possible	♦ IJ13
Catch	The actuator controls a small catch. The catch either enables or disables movement of an ink pusher that is controlled in a bulk manner.	♦ Very low actuator energy ♦ Very small actuator size	♦ Complex construction ♦ Requires external force ♦ Unsuitable for pigmented inks	♦ IJ10
Buckle plate	A buckle plate can be used to change a slow actuator into a fast motion. It can also convert a high force, low travel actuator into a high travel, medium force motion.	♦ Very fast movement achievable	♦ Must stay within elastic limits of the materials for long device life ♦ High stresses involved ♦ Generally high power requirement	♦ S. Hirata et al, "An Ink-jet Head ...", Proc. IEEE MEMS, Feb. 1996, pp 418-423. ♦ IJ18, IJ27

Tapered magnetic pole	A tapered magnetic pole can increase travel at the expense of force.	♦ Linearizes the magnetic force/distance curve	♦ Complex construction	♦ IJ14
Lever	A lever and fulcrum is used to transform a motion with small travel and high force into a motion with longer travel and lower force. The lever can also reverse the direction of travel.	♦ Matches low travel actuator with higher travel requirements ♦ Fulcrum area has no linear movement, and can be used for a fluid seal	♦ High stress around the fulcrum	♦ IJ32, IJ36, IJ37
Rotary impeller	The actuator is connected to a rotary impeller. A small angular deflection of the actuator results in a rotation of the impeller vanes, which push the ink against stationary vanes and out of the nozzle.	♦ High mechanical advantage ♦ The ratio of force to travel of the actuator can be matched to the nozzle requirements by varying the number of impeller vanes	♦ Complex construction ♦ Unsuitable for pigmented inks	♦ IJ28
Acoustic lens	A refractive or diffractive (e.g. zone plate) acoustic lens is used to concentrate sound waves.	♦ No moving parts	♦ Large area required ♦ Only relevant for acoustic ink jets	♦ 1993 Hadimioglu et al, EUP 550,192 ♦ 1993 Elrod et al, EUP 572,220
Sharp conductive point	A sharp point is used to concentrate an electrostatic field.	♦ Simple construction	♦ Difficult to fabricate using standard VLSI processes for a surface ejecting ink-jet ♦ Only relevant for electrostatic ink jets	♦ Tone-jet

Actuator motion

Actuator motion	Description	Advantages	Disadvantages	Examples
Volume expansion	The volume of the actuator changes, pushing the ink in all directions.	♦ Simple construction in the case of thermal ink jet	♦ High energy is typically required to achieve volume expansion. This leads to thermal stress, cavitation, and kogation in thermal ink jet implementations	♦ Hewlett-Packard Thermal Inkjet ♦ Canon Bubblejet
Linear, normal to chip surface	The actuator moves in a direction normal to the print head surface. The nozzle is typically in the line of movement.	♦ Efficient coupling to ink drops ejected normal to the surface	♦ High fabrication complexity may be required to achieve perpendicular motion	♦ IJ01, IJ02, IJ04, IJ07 ♦ IJ11, IJ14
Linear, parallel to chip surface	The actuator moves parallel to the print head surface. Drop ejection may still be normal to the surface.	♦ Suitable for planar fabrication	♦ Fabrication complexity ♦ Friction ♦ Stiction	♦ IJ12, IJ13, IJ15, IJ33, ♦ IJ34, IJ35, IJ36
Membrane push	An actuator with a high force but small area is used to push a stiff membrane that is in contact with the ink.	♦ The effective area of the actuator becomes the membrane area	♦ Fabrication complexity ♦ Actuator size ♦ Difficulty of integration in a VLSI process	♦ 1982 Howkins USP 4,459,601
Rotary	The actuator causes the rotation of some element, such a grill or impeller	♦ Rotary levers may be used to increase travel ♦ Small chip area requirements	♦ Device complexity ♦ May have friction at a pivot point	♦ IJ05, IJ08, IJ13, IJ28

Bend	The actuator bends when energized. This may be due to differential thermal expansion, piezoelectric expansion, magnetostriction, or other form of relative dimensional change.	♦ A very small change in dimensions can be converted to a large motion.	♦ Requires the actuator to be made from at least two distinct layers, or to have a thermal difference across the actuator	♦ 1970 Kyser et al USP 3,946,398 ♦ 1973 Stemme USP 3,747,120 ♦ IJ03, IJ09, IJ10, IJ19 ♦ IJ23, IJ24, IJ25, IJ29 ♦ IJ30, IJ31, IJ33, IJ34 ♦ IJ35
Swivel	The actuator swivels around a central pivot. This motion is suitable where there are opposite forces applied to opposite sides of the paddle, e.g. Lorenz force.	♦ Allows operation where the net linear force on the paddle is zero ♦ Small chip area requirements	♦ Inefficient coupling to the ink motion	♦ IJ06
Straighten	The actuator is normally bent, and straightens when energized.	♦ Can be used with shape memory alloys where the austenic phase is planar	♦ Requires careful balance of stresses to ensure that the quiescent bend is accurate	♦ IJ26, IJ32
Double bend	The actuator bends in one direction when one element is energized, and bends the other way when another element is energized.	♦ One actuator can be used to power two nozzles. ♦ Reduced chip size. ♦ Not sensitive to ambient temperature	♦ Difficult to make the drops ejected by both bend directions identical. ♦ A small efficiency loss compared to equivalent single bend actuators.	♦ IJ36, IJ37, IJ38
Shear	Energizing the actuator causes a shear motion in the actuator material.	♦ Can increase the effective travel of piezoelectric actuators	♦ Not readily applicable to other actuator mechanisms	♦ 1985 Fishbeck USP 4,584,590

Radial constriction	The actuator squeezes an ink reservoir, forcing ink from a constricted nozzle.	♦ Relatively easy to fabricate single nozzles from glass tubing as macroscopic structures	♦ High force required ♦ Inefficient ♦ Difficult to integrate with VLSI processes	♦ 1970 Zoltan USP 3,683,212
Coil / uncoil	A coiled actuator uncoils or coils more tightly. The motion of the free end of the actuator ejects the ink.	♦ Easy to fabricate as a planar VLSI process ♦ Small area required, therefore low cost	♦ Difficult to fabricate for non-planar devices ♦ Poor out-of-plane stiffness	♦ IJ17, IJ21, IJ34, IJ35
Bow	The actuator bows (or buckles) in the middle when energized.	♦ Can increase the speed of travel ♦ Mechanically rigid	♦ Maximum travel is constrained ♦ High force required	♦ IJ16, IJ18, IJ27
Push-Pull	Two actuators control a shutter. One actuator pulls the shutter, and the other pushes it.	♦ The structure is pinned at both ends, so has a high out-of-plane rigidity	♦ Not readily suitable for inkjets which directly push the ink	♦ IJ18
Curl inwards	A set of actuators curl inwards to reduce the volume of ink that they enclose.	♦ Good fluid flow to the region behind the actuator increases efficiency	♦ Design complexity	♦ IJ20, IJ42
Curl outwards	A set of actuators curl outwards, pressurizing ink in a chamber surrounding the actuators, and expelling ink from a nozzle in the chamber.	♦ Relatively simple construction	♦ Relatively large chip area	♦ IJ43
Iris	Multiple vanes enclose a volume of ink. These simultaneously rotate, reducing the volume between the vanes.	♦ High efficiency ♦ Small chip area	♦ High fabrication complexity ♦ Not suitable for pigmented inks	♦ IJ22

Acoustic vibration	The actuator vibrates at a high frequency.	♦ The actuator can be physically distant from the ink	♦ Large area required for efficient operation at useful frequencies ♦ Acoustic coupling and crosstalk ♦ Complex drive circuitry ♦ Poor control of drop volume and position	♦ 1993 Hadimioglu et al, EUP 550,192 ♦ 1993 Elrod et al, EUP 572,220
None	In various ink jet designs the actuator does not move.	♦ No moving parts	♦ Various other tradeoffs are required to eliminate moving parts	♦ Silverbrook, EP 0771 658 A2 and related patent applications ♦ Tone-jet

Nozzle refill method

Nozzle refill method	Description	Advantages	Disadvantages	Examples
Surface tension	After the actuator is energized, it typically returns rapidly to its normal position. This rapid return sucks in air through the nozzle opening. The ink surface tension at the nozzle then exerts a small force restoring the meniscus to a minimum area.	♦ Fabrication simplicity ♦ Operational simplicity	♦ Low speed ♦ Surface tension force relatively small compared to actuator force ♦ Long refill time usually dominates the total repetition rate	♦ Thermal inkjet ♦ Piezoelectric inkjet ♦ IJ01-IJ07, IJ10-IJ14 ♦ IJ16, IJ20, IJ22-IJ45

Shuttered oscillating ink pressure	Ink to the nozzle chamber is provided at a pressure that oscillates at twice the drop ejection frequency. When a drop is to be ejected, the shutter is opened for 3 half cycles: drop ejection, actuator return, and refill.	♦ High speed ♦ Low actuator energy, as the actuator need only open or close the shutter, instead of ejecting the ink drop	♦ Requires common ink pressure oscillator ♦ May not be suitable for pigmented inks	♦ IJ08, IJ13, IJ15, IJ17 ♦ IJ18, IJ19, IJ21
Refill actuator	After the main actuator has ejected a drop a second (refill) actuator is energized. The refill actuator pushes ink into the nozzle chamber. The refill actuator returns slowly, to prevent its return from emptying the chamber again.	♦ High speed, as the nozzle is actively refilled	♦ Requires two independent actuators per nozzle	♦ IJ09
Positive ink pressure	The ink is held a slight positive pressure. After the ink drop is ejected, the nozzle chamber fills quickly as surface tension and ink pressure both operate to refill the nozzle.	♦ High refill rate, therefore a high drop repetition rate is possible	♦ Surface spill must be prevented ♦ Highly hydrophobic print head surfaces are required	♦ Silverbrook, EP 0771 658 A2 and related patent applications ♦ Alternative for: ♦ IJ01-IJ07, IJ10-IJ14 ♦ IJ16, IJ20, IJ22-IJ45

Method of restricting back-flow through inlet

Inlet back-flow restriction method	Description	Advantages	Disadvantages	Examples

Long inlet channel	The ink inlet channel to the nozzle chamber is made long and relatively narrow, relying on viscous drag to reduce inlet back-flow.	♦ Design simplicity ♦ Operational simplicity ♦ Reduces crosstalk	♦ Restricts refill rate ♦ May result in a relatively large chip area ♦ Only partially effective	♦ Thermal inkjet ♦ Piezoelectric inkjet ♦ IJ42, IJ43
Positive ink pressure	The ink is under a positive pressure, so that in the quiescent state some of the ink drop already protrudes from the nozzle. This reduces the pressure in the nozzle chamber which is required to eject a certain volume of ink. The reduction in chamber pressure results in a reduction in ink pushed out through the inlet.	♦ Drop selection and separation forces can be reduced ♦ Fast refill time	♦ Requires a method (such as a nozzle rim or effective hydrophobizing, or both) to prevent flooding of the ejection surface of the print head.	♦ Silverbrook, EP 0771 658 A2 and related patent applications ♦ Possible operation of the following: ♦ IJ01-IJ07, IJ09- IJ12 ♦ IJ14, IJ16, IJ20, IJ22, ♦ IJ23-IJ34, IJ36- IJ41 ♦ IJ44
Baffle	One or more baffles are placed in the inlet ink flow. When the actuator is energized, the rapid ink movement creates eddies which restrict the flow through the inlet. The slower refill process is unrestricted, and does not result in eddies.	♦ The refill rate is not as restricted as the long inlet method. ♦ Reduces crosstalk	♦ Design complexity ♦ May increase fabrication complexity (e.g. Tektronix hot melt Piezoelectric print heads).	♦ HP Thermal Ink Jet ♦ Tektronix piezoelectric ink jet
Flexible flap restricts inlet	In this method recently disclosed by Canon, the expanding actuator (bubble) pushes on a flexible flap that restricts the inlet.	♦ Significantly reduces back-flow for edge-shooter thermal ink jet devices	♦ Not applicable to most inkjet configurations ♦ Increased fabrication complexity ♦ Inelastic deformation of polymer flap results in creep over extended use	♦ Canon

Inlet filter	A filter is located between the ink inlet and the nozzle chamber. The filter has a multitude of small holes or slots, restricting ink flow. The filter also removes particles which may block the nozzle.	♦ Additional advantage of ink filtration ♦ Ink filter may be fabricated with no additional process steps	♦ Restricts refill rate ♦ May result in complex construction	♦ IJ04, IJ12, IJ24, IJ27 ♦ IJ29, IJ30
Small inlet compared to nozzle	The ink inlet channel to the nozzle chamber has a substantially smaller cross section than that of the nozzle, resulting in easier ink egress out of the nozzle than out of the inlet.	♦ Design simplicity	♦ Restricts refill rate ♦ May result in a relatively large chip area ♦ Only partially effective	♦ IJ02, IJ37, IJ44
Inlet shutter	A secondary actuator controls the position of a shutter, closing off the ink inlet when the main actuator is energized.	♦ Increases speed of the ink-jet print head operation	♦ Requires separate refill actuator and drive circuit	♦ IJ09
The inlet is located behind the ink-pushing surface	The method avoids the problem of inlet back-flow by arranging the ink-pushing surface of the actuator between the inlet and the nozzle.	♦ Back-flow problem is eliminated	♦ Requires careful design to minimize the negative pressure behind the paddle	♦ IJ01, IJ03, IJ05, IJ06 ♦ IJ07, IJ10, IJ11, IJ14 ♦ IJ16, IJ22, IJ23, IJ25 ♦ IJ28, IJ31, IJ32, IJ33 ♦ IJ34, IJ35, IJ36, IJ39 ♦ IJ40, IJ41
Part of the actuator moves to shut off the inlet	The actuator and a wall of the ink chamber are arranged so that the motion of the actuator closes off the inlet.	♦ Significant reductions in back-flow can be achieved ♦ Compact designs possible	♦ Small increase in fabrication complexity	♦ IJ07, IJ20, IJ26, IJ38

Nozzle actuator does not result in ink back-flow	In some configurations of ink jet, there is no expansion or movement of an actuator which may cause ink back-flow through the inlet.	♦ Ink back-flow problem is eliminated	♦ None related to ink back-flow on actuation	♦ Silverbrook, EP 0771 658 A2 and related patent applications ♦ Valve-jet ♦ Tone-jet ♦ IJ08, IJ13, IJ15, IJ17 ♦ IJ18, IJ19, IJ21

Nozzle Clearing Method

Nozzle Clearing method	Description	Advantages	Disadvantages	Examples
Normal nozzle firing	All of the nozzles are fired periodically, before the ink has a chance to dry. When not in use the nozzles are sealed (capped) against air. The nozzle firing is usually performed during a special clearing cycle, after first moving the print head to a cleaning station.	♦ No added complexity on the print head	♦ May not be sufficient to displace dried ink	♦ Most ink jet systems ♦ IJ01- IJ07, IJ09-IJ12 ♦ IJ14, IJ16, IJ20, IJ22 ♦ IJ23- IJ34, IJ36-IJ45
Extra power to ink heater	In systems which heat the ink, but do not boil it under normal situations, nozzle clearing can be achieved by over-powering the heater and boiling ink at the nozzle.	♦ Can be highly effective if the heater is adjacent to the nozzle	♦ Requires higher drive voltage for clearing ♦ May require larger drive transistors	♦ Silverbrook, EP 0771 658 A2 and related patent applications

Rapid succession of actuator pulses	The actuator is fired in rapid succession. In some configurations, this may cause heat build-up at the nozzle which boils the ink, clearing the nozzle. In other situations, it may cause sufficient vibrations to dislodge clogged nozzles.	♦ Does not require extra drive circuits on the print head ♦ Can be readily controlled and initiated by digital logic	♦ Effectiveness depends substantially upon the configuration of the inkjet nozzle	♦ May be used with: ♦ IJ01-IJ07, IJ09- IJ11 ♦ IJ14, IJ16, IJ20, IJ22 ♦ IJ23-IJ25, IJ27-IJ34 ♦ IJ36-IJ45
Extra power to ink pushing actuator	Where an actuator is not normally driven to the limit of its motion, nozzle clearing may be assisted by providing an enhanced drive signal to the actuator.	♦ A simple solution where applicable	♦ Not suitable where there is a hard limit to actuator movement	♦ May be used with: ♦ IJ03, IJ09, IJ16, IJ20 ♦ IJ23, IJ24, IJ25, IJ27 ♦ IJ29, IJ30, IJ31, IJ32 ♦ IJ39, IJ40, IJ41, IJ42 ♦ IJ43, IJ44, IJ45

Acoustic resonance	An ultrasonic wave is applied to the ink chamber. This wave is of an appropriate amplitude and frequency to cause sufficient force at the nozzle to clear blockages. This is easiest to achieve if the ultrasonic wave is at a resonant frequency of the ink cavity.	♦ A high nozzle clearing capability can be achieved ♦ May be implemented at very low cost in systems which already include acoustic actuators	♦ High implementation cost if system does not already include an acoustic actuator	♦ IJ08, IJ13, IJ15, IJ17 ♦ IJ18, IJ19, IJ21
Nozzle clearing plate	A microfabricated plate is pushed against the nozzles. The plate has a post for every nozzle. The array of posts	♦ Can clear severely clogged nozzles	♦ Accurate mechanical alignment is required ♦ Moving parts are required ♦ There is risk of damage to the nozzles ♦ Accurate fabrication is required	♦ Silverbrook, EP 0771 658 A2 and related patent applications
Ink pressure pulse	The pressure of the ink is temporarily increased so that ink streams from all of the nozzles. This may be used in conjunction with actuator energizing.	♦ May be effective where other methods cannot be used	♦ Requires pressure pump or other pressure actuator ♦ Expensive ♦ Wasteful of ink	♦ May be used with all IJ series ink jets
Print head wiper	A flexible 'blade' is wiped across the print head surface. The blade is usually fabricated from a flexible polymer, e.g. rubber or synthetic elastomer.	♦ Effective for planar print head surfaces ♦ Low cost	♦ Difficult to use if print head surface is non-planar or very fragile ♦ Requires mechanical parts ♦ Blade can wear out in high volume print systems	♦ Many ink jet systems

Separate ink boiling heater	A separate heater is provided at the nozzle although the normal drop e-ection mechanism does not require it. The heaters do not require individual drive circuits, as many nozzles can be cleared simultaneously, and no imaging is required.	♦ Can be effective where other nozzle clearing methods cannot be used ♦ Can be implemented at no additional cost in some inkjet configurations	♦ Fabrication complexity	♦ Can be used with many IJ series ink jets

Nozzle plate construction

Nozzle plate construction	Description	Advantages	Disadvantages	Examples
Electroformed nickel	A nozzle plate is separately fabricated from electroformed nickel, and bonded to the print head chip.	♦ Fabrication simplicity	♦ High temperatures and pressures are required to bond nozzle plate ♦ Minimum thickness constraints ♦ Differential thermal expansion	♦ Hewlett Packard Thermal Inkjet
Laser ablated or drilled polymer	Individual nozzle holes are ablated by an intense UV laser in a nozzle plate, which is typically a polymer such as polyimide or polysulphone	♦ No masks required ♦ Can be quite fast ♦ Some control over nozzle profile is possible ♦ Equipment required is relatively low cost	♦ Each hole must be individually formed ♦ Special equipment required ♦ Slow where there are many thousands of nozzles per print head ♦ May produce thin burrs at exit holes	♦ Canon Bubblejet ♦ 1988 Sercel et al., SPIE, Vol. 998 Excimer Beam Applications, pp. 76-83 ♦ 1993 Watanabe et al., USP 5,208,604

Silicon micro-machined	A separate nozzle plate is micromachined from single crystal silicon, and bonded to the print head wafer.	♦ High accuracy is attainable	♦ Two part construction ♦ High cost ♦ Requires precision alignment ♦ Nozzles may be clogged by adhesive	♦ K. Bean, IEEE Transactions on Electron Devices, Vol. ED-25, No. 10, 1978, pp 1185-1195 ♦ Xerox 1990 Hawkins et al., USP 4,899,181
Glass capillaries	Fine glass capillaries are drawn from glass tubing. This method has been used for making individual nozzles, but is difficult to use for bulk manufacturing of print heads with thousands of nozzles.	♦ No expensive equipment required ♦ Simple to make single nozzles	♦ Very small nozzle sizes are difficult to form ♦ Not suited for mass production	♦ 1970 Zoltan USP 3,683,212

Monolithic, surface micro-machined using VLSI lithographic processes	The nozzle plate is deposited as a layer using standard VLSI deposition techniques. Nozzles are etched in the nozzle plate using VLSI lithography and etching.	♦ High accuracy (<1 μm) ♦ Monolithic ♦ Low cost ♦ Existing processes can be used	♦ Requires sacrificial layer under the nozzle plate to form the nozzle chamber ♦ Surface may be fragile to the touch	♦ Silverbrook, EP 0771 658 A2 and related patent applications ♦ IJ01, IJ02, IJ04, IJ11 ♦ IJ12, IJ17, IJ18, IJ20 ♦ IJ22, IJ24, IJ27, IJ28 ♦ IJ29, IJ30, IJ31, IJ32 ♦ IJ33, IJ34, IJ36, IJ37 ♦ IJ38, IJ39, IJ40, IJ41 ♦ IJ42, IJ43, IJ44
Monolithic, etched through substrate	The nozzle plate is a buried etch stop in the wafer. Nozzle chambers are etched in the front of the wafer, and the wafer is thinned from the back side. Nozzles are then etched in the etch stop layer.	♦ High accuracy (<1 μm) ♦ Monolithic ♦ Low cost ♦ No differential expansion	♦ Requires long etch times ♦ Requires a support wafer	♦ IJ03, IJ05, IJ06, IJ07 ♦ IJ08, IJ09, IJ10, IJ13 ♦ IJ14, IJ15, IJ16, IJ19 ♦ IJ21, IJ23, IJ25, IJ26

No nozzle plate	Various methods have been tried to eliminate the nozzles entirely, to prevent nozzle clogging. These include thermal bubble mechanisms and acoustic lens mechanisms	♦ No nozzles to become clogged	♦ Difficult to control drop position accurately ♦ Crosstalk problems	♦ Ricoh 1995 Sekiya et al USP 5,412,413 ♦ 1993 Hadimioglu et al EUP 550,192 ♦ 1993 Elrod et al EUP 572,220
Trough	Each drop ejector has a trough through which a paddle moves. There is no nozzle plate.	♦ Reduced manufacturing complexity ♦ Monolithic	♦ Drop firing direction is sensitive to wicking.	♦ IJ35
Nozzle slit instead of individual nozzles	The elimination of nozzle holes and replacement by a slit encompassing many actuator positions reduces nozzle clogging, but increases crosstalk due to ink surface waves	♦ No nozzles to become clogged	♦ Difficult to control drop position accurately ♦ Crosstalk problems	♦ 1989 Saito et al USP 4,799,068

<u>Drop ejection direction</u>

Ejection direction	Description	Advantages	Disadvantages	Examples

Edge. ('edge shooter')	Ink flow is along the surface of the chip, and ink drops are ejected from the chip edge.	♦ Simple construction ♦ No silicon etching required ♦ Good heat sinking via substrate ♦ Mechanically strong ♦ Ease of chip handing	♦ Nozzles limited to edge ♦ High resolution is difficult ♦ Fast color printing requires one print head per color	♦ Canon Bubblejet 1979 Endo et al GB patent 2,007,162 ♦ Xerox heater-in-pit 1990 Hawkins et al USP 4,899,181 ♦ Tone-jet
Surface ('roof shooter')	Ink flow is along the surface of the chip, and ink drops are ejected from the chip surface, normal to the plane of the chip.	♦ No bulk silicon etching required ♦ Silicon can make an effective heat sink ♦ Mechanical strength	♦ Maximum ink flow is severely restricted	♦ Hewlett-Packard TIJ 1982 Vaught et al USP 4,490,728 ♦ IJ02, IJ11, IJ12, IJ20 ♦ IJ22
Through chip, forward ('up shooter')	Ink flow is through the chip, and ink drops are ejected from the front surface of the chip.	♦ High ink flow ♦ Suitable for pagewidth print ♦ High nozzle packing density therefore low manufacturing cost	♦ Requires bulk silicon etching	♦ Silverbrook, EP 0771 658 A2 and related patent applications ♦ IJ04, IJ17, IJ18, IJ24 ♦ IJ27-IJ45

Through chip, reverse ('down shooter')	Ink flow is through the chip, and ink drops are ejected from the rear surface of the chip.	♦ High ink flow ♦ Suitable for pagewidth print ♦ High nozzle packing density therefore low manufacturing cost	♦ Requires wafer thinning ♦ Requires special handling during manufacture	♦ IJ01, IJ03, IJ05, IJ06 ♦ IJ07, IJ08, IJ09, IJ10 ♦ IJ13, IJ14, IJ15, IJ16 ♦ IJ19, IJ21, IJ23, IJ25 ♦ IJ26
Through actuator	Ink flow is through the actuator, which is not fabricated as part of the same substrate as the drive transistors.	♦ Suitable for piezoelectric print heads	♦ Pagewidth print heads require several thousand connections to drive circuits ♦ Cannot be manufactured in standard CMOS fabs ♦ Complex assembly required	♦ Epson Stylus ♦ Tektronix hot melt piezoelectric ink jets

Ink type

Ink type	Description	Advantages	Disadvantages	Examples

Aqueous, dye	Water based ink which typically contains: water, dye, surfactant, humectant, and biocide. Modern ink dyes have high water-fastness, light fastness	♦ Environmentally friendly ♦ No odor	♦ Slow drying ♦ Corrosive ♦ Bleeds on paper ♦ May strikethrough ♦ Cockles paper	♦ Most existing inkjets ♦ All IJ series ink jets ♦ Silverbrook, EP 0771 658 A2 and related patent applications
Aqueous, pigment	Water based ink which typically contains: water, pigment, surfactant, humectant, and biocide. Pigments have an advantage in reduced bleed, wicking and strikethrough.	♦ Environmentally friendly ♦ No odor ♦ Reduced bleed ♦ Reduced wicking ♦ Reduced strikethrough	♦ Slow drying ♦ Corrosive ♦ Pigment may clog nozzles ♦ Pigment may clog actuator mechanisms ♦ Cockles paper	♦ IJ02, IJ04, IJ21, IJ26 ♦ IJ27, IJ30 ♦ Silverbrook, EP 0771 658 A2 and related patent applications ♦ Piezoelectric ink-jets ♦ Thermal ink jets (with significant restrictions)
Methyl Ethyl Ketone (MEK)	MEK is a highly volatile solvent used for industrial printing on difficult surfaces such as aluminum cans.	♦ Very fast drying ♦ Prints on various substrates such as metals and plastics	♦ Odorous ♦ Flammable	♦ All IJ series ink jets

Alcohol (ethanol, 2-butanol, and others)	Alcohol based inks can be used where the printer must operate at temperatures below the freezing point of water. An example of this is in-camera consumer photographic printing.	♦ Fast drying ♦ Operates at sub-freezing temperatures ♦ Reduced paper cockle ♦ Low cost	♦ Slight odor ♦ Flammable	♦ All IJ series ink jets
Phase change (hot melt)	The ink is solid at room temperature, and is melted in the print head before jetting. Hot melt inks are usually wax based, with a melting point around 80 °C. After jetting the ink freezes almost instantly upon contacting the print medium or a transfer roller.	♦ No drying time- ink instantly freezes on the print medium ♦ Almost any print medium can be used ♦ No paper cockle occurs ♦ No wicking occurs ♦ No bleed occurs ♦ No strikethrough occurs	♦ High viscosity ♦ Printed ink typically has a 'waxy' feel ♦ Printed pages may 'block' ♦ Ink temperature may be above the curie point of permanent magnets ♦ Ink heaters consume power ♦ Long warm-up time	♦ Tektronix hot melt piezoelectric ink jets ♦ 1989 Nowak USP 4,820,346 ♦ All IJ series ink jets
Oil	Oil based inks are extensively used in offset printing. They have advantages in improved characteristics on paper (especially no wicking or cockle). Oil soluble dies and pigments are required.	♦ High solubility medium for some dyes ♦ Does not cockle paper ♦ Does not wick through paper	♦ High viscosity: this is a significant limitation for use in inkjets, which usually require a low viscosity. Some short chain and multi-branched oils have a sufficiently low viscosity. ♦ Slow drying	♦ All IJ series ink jets

Ink Jet Printing

[0099] A large number of new forms of ink jet printers have been developed to facilitate alternative ink jet technologies for the image processing and data distribution system. Various combinations of ink jet devices can be included in printer devices incorporated as part of the present invention. Australian Provisional Patent Applications relating to these ink jets which are specifically incorporated by cross reference include:

Australian Provisional Number	Filing Date	Title
PO8066	15-Jul-97	Image Creation Method and Apparatus (IJ01)
PO8072	15-Jul-97	Image Creation Method and Apparatus (IJ02)
PO8040	15-Jul-97	Image Creation Method and Apparatus (IJ03)
PO8071	15-Jul-97	Image Creation Method and Apparatus (IJ04)
PO8047	15-Jul-97	Image Creation Method and Apparatus (IJ05)
PO8035	15-Jul-97	Image Creation Method and Apparatus (IJ06)
PO8044	15-Jul-97	Image Creation Method and Apparatus (IJ07)
PO8063	15-Jul-97	Image Creation Method and Apparatus (IJ08)
PO8057	15-Jul-97	Image Creation Method and Apparatus (IJ09)
PO8056	15-Jul-97	Image Creation Method and Apparatus (IJ10)
PO8069	15-Jul-97	Image Creation Method and Apparatus (IJ11)
PO8049	15-Jul-97	Image Creation Method and Apparatus (IJ12)
PO8036	15-Jul-97	Image Creation Method and Apparatus (IJ13)
PO8048	15-Jul-97	Image Creation Method and Apparatus (IJ14)
PO8070	15-Jul-97	Image Creation Method and Apparatus (IJ15)
PO8067	15-Jul-97	Image Creation Method and Apparatus (IJ16)
PO8001	15-Jul-97	Image Creation Method and Apparatus (IJ17)
PO8038	15-Jul-97	Image Creation Method and Apparatus (IJ18)
PO8033	15-Jul-97	Image Creation Method and Apparatus (IJ19)
PO8002	15-Jul-97	Image Creation Method and Apparatus (IJ20)
PO8068	15-Jul-97	Image Creation Method and Apparatus (IJ21)
PO8062	15-Jul-97	Image Creation Method and Apparatus (IJ22)
PO8034	15-Jul-97	Image Creation Method and Apparatus (IJ23)
PO8039	15-Jul-97	Image Creation Method and Apparatus (IJ24)
PO8041	15-Jul-97	Image Creation Method and Apparatus (IJ25)
PO8004	15-Jul-97	Image Creation Method and Apparatus (IJ26)
PO8037	15-Jul-97	Image Creation Method and Apparatus (IJ27)
PO8043	15-Jul-97	Image Creation Method and Apparatus (IJ28)
PO8042	15-Jul-97	Image Creation Method and Apparatus (IJ29)
PO8064	15-Jul-97	Image Creation Method and Apparatus (IJ30)
PO9389	23-Sep-97	Image Creation Method and Apparatus (IJ31)
PO9391	23-Sep-97	Image Creation Method and Apparatus (IJ32)
PP0888	12-Dec-97	Image Creation Method and Apparatus (IJ33)

(continued)

Australian Provisional Number	Filing Date	Title
PP0891	12-Dec-97	Image Creation Method and Apparatus (IJ34)
PP0890	12-Dec-97	Image Creation Method and Apparatus (IJ35)
PP0873	12-Dec-97	Image Creation Method and Apparatus (IJ36)
PP0993	12-Dec-97	Image Creation Method and Apparatus (IJ37)
PP0890	12-Dec-97	Image Creation Method and Apparatus (IJ38)
PP1398	19-Jan-98	An Image Creation Method and Apparatus (IJ39)
PP2592	25-Mar-98	An Image Creation Method and Apparatus (IJ40)
PP2593	25-Mar-98	Image Creation Method and Apparatus (IJ41)
PP3991	9-Jun-98	Image Creation Method and Apparatus (IJ42)
PP3987	9-Jun-98	Image Creation Method and Apparatus (IJ43)
PP3985	9-Jun-98	Image Creation Method and Apparatus (IJ44)
PP3983	9-Jun-98	Image Creation Method and Apparatus (IJ45)

Ink Jet Manufacturing

[0100] Further, the present application may utilize advanced semiconductor fabrication techniques in the construction of large arrays of ink jet printers. Suitable manufacturing techniques are described in the following Australian provisional patent specifications incorporated here by cross-reference:

Australian Provisional Number	Filing Date	Title
PO7935	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM01)
PO7936	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM02)
PO7937	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM03)
PO8061	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM04)
PO8054	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM05)
PO8065	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM06)
PO8055	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM07)
PO8053	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM08)
PO8078	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM09)
PO7933	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM10)
PO7950	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM11)
PO7949	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM12)
PO8060	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM13)
PO8059	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM14)
PO8073	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM15)
PO8076	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM16)
PO8075	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM17)
PO8079	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM18)

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Australian Provisional Number	Filing Date	Title
PO8050	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM19)
PO8052	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM20)
PO7948	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM21)
PO7951	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM22)
PO8074	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM23)
PO7941	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM24)
PO8077	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM25)
PO8058	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM26)
PO8051	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM27)
PO8045	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM28)
PO7952	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM29)
PO8046	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM30)
PO8503	11-Aug-97	A Method of Manufacture of an Image Creation Apparatus (IJM30a)
PO9390	23-Sep-97	A Method of Manufacture of an Image Creation Apparatus (IJM31)
PO9392	23-Sep-97	A Method of Manufacture of an Image Creation Apparatus (IJM32)
PP0889	12-Dec-97	A Method of Manufacture of an Image Creation Apparatus (IJM35)
PP0887	12-Dec-97	A Method of Manufacture of an Image Creation Apparatus (IJM36)
PP0882	12-Dec-97	A Method of Manufacture of an Image Creation Apparatus (IJM37)
PP0874	12-Dec-97	A Method of Manufacture of an Image Creation Apparatus (IJM38)
PP1396	19-Jan-98	A Method of Manufacture of an Image Creation Apparatus (IJM39)
PP2591	25-Mar-98	A Method of Manufacture of an Image Creation Apparatus (IJM41)
PP3989	9-Jun-98	A Method of Manufacture of an Image Creation Apparatus (IJM40)
PP3990	9-Jun-98	A Method of Manufacture of an Image Creation Apparatus (IJM42)
PP3986	9-Jun-98	A Method of Manufacture of an Image Creation Apparatus (IJM43)
PP3984	9-Jun-98	A Method of Manufacture of an Image Creation Apparatus (IJM44)
PP3982	9-Jun-98	A Method of Manufacture of an Image Creation Apparatus (IJM45)

Fluid Supply

[0101] Further, the present application may utilize an ink delivery system to the ink jet head. Delivery systems relating to the supply of ink to a series of ink jet nozzles are described in the following Australian provisional patent specifications, the disclosure of which are hereby incorporated by cross-reference:

Australian Provisional Number	Filing Date	Title
PO8003	15-Jul-97	Supply Method and Apparatus (F1)
PO8005	15-Jul-97	Supply Method and Apparatus (F2)
PO9404	23-Sep-97	A Device and Method (F3)

MEMS Technology

[0102] Further, the present application may utilize advanced semiconductor microelectromechanical techniques in the construction of large arrays of ink jet printers. Suitable microelectromechanical techniques are described in the following Australian provisional patent specifications incorporated here by cross-reference:

Australian Provisional Number	Filing Date	Title
PO7943	15-Jul-97	A device (MEMS01)
PO8006	15-Jul-97	A device (MEMS02)
PO8007	15-Jul-97	A device (MEMS03)
PO8008	15-Jul-97	A device (MEMS04)
PO8010	15-Jul-97	A device (MEMS05)
PO8011	15-Jul-97	A device (MEMS06)
PO7947	15-Jul-97	A device (MEMS07)
PO7945	15-Jul-97	A device (MEMS08)
PO7944	15-Jul-97	A device (MEMS09)
PO7946	15-Jul-97	A device (MEMS10)
PO9393	23-Sep-97	A Device and Method (MEMS11)
PP0875	12-Dec-97	A Device (MEMS12)
PP0894	12-Dec-97	A Device and Method (MEMS13)

IR Technologies

[0103] Further, the present application may include the utilization of a disposable camera system such as those described in the following Australian provisional patent specifications incorporated here by cross-reference:

Australian Provisional Number	Filing Date	Title
PP0895	12-Dec-97	An Image Creation Method and Apparatus (IR01)
PP0870	12-Dec-97	A Device and Method (IR02)
PP0869	12-Dec-97	A Device and Method (IR04)
PP0887	12-Dec-97	Image Creation Method and Apparatus (IR05)
PP0885	12-Dec-97	An Image Production System (IR06)
PP0884	12-Dec-97	Image Creation Method and Apparatus (IR10)
PP0886	12-Dec-97	Image Creation Method and Apparatus (IR12)
PP0871	12-Dec-97	A Device and Method (IR13)
PP0876	12-Dec-97	An Image Processing Method and Apparatus (IR14)
PP0877	12-Dec-97	A Device and Method (IR16)
PP0878	12-Dec-97	A Device and Method (IR17)
PP0879	12-Dec-97	A Device and Method (IR18)
PP0883	12-Dec-97	A Device and Method (IR19)
PP0880	12-Dec-97	A Device and Method (IR20)
PP0881	12-Dec-97	A Device and Method (IR21)

DotCard Technologies

[0104] Further, the present application may include the utilization of a data distribution system such as that described in the following Australian provisional patent specifications incorporated here by cross-reference:

Australian Provisional Number	Filing Date	Title
PP2370	16-Mar-98	Data Processing Method and Apparatus (Dot01)
PP2371	16-Mar-98	Data Processing Method and Apparatus (Dot02)

Artcam Technologies

[0105] Further, the present application may include the utilization of camera and data processing techniques such as an Artcam type device as described in the following Australian provisional patent specifications incorporated here by cross-reference:

Australian Provisional Number	Filing Date	Title
PO7991	15-Jul-97	Image Processing Method and Apparatus (ART01)
PO8505	11-Aug-97	Image Processing Method and Apparatus (ART01a)
PO7988	15-Jul-97	Image Processing Method and Apparatus (ART02)
PO7993	15-Jul-97	Image Processing Method and Apparatus (ART03)
PO8012	15-Jul-97	Image Processing Method and Apparatus (ART05)
PO8017	15-Jul-97	Image Processing Method and Apparatus (ART06)
PO8014	15-Jul-97	Media Device (ART07)
PO8025	15-Jul-97	Image Processing Method and Apparatus (ART08)
PO8032	15-Jul-97	Image Processing Method and Apparatus (ART09)
PO7999	15-Jul-97	Image Processing Method and Apparatus (ART10)
PO7998	15-Jul-97	Image Processing Method and Apparatus (ART11)
PO8031	15-Jul-97	Image Processing Method and Apparatus (ART12)
PO8030	15-Jul-97	Media Device (ART13)
PO8498	11-Aug-97	Image Processing Method and Apparatus (ART14)
PO7997	15-Jul-97	Media Device (ART15)
PO7979	15-Jul-97	Media Device (ART16)
PO8015	15-Jul-97	Media Device (ART17)
PO7978	15-Jul-97	Media Device (ART18)
PO7982	15-Jul-97	Data Processing Method and Apparatus (ART19)
PO7989	15-Jul-97	Data Processing Method and Apparatus (ART20)
PO8019	15-Jul-97	Media Processing Method and Apparatus (ART21)
PO7980	15-Jul-97	Image Processing Method and Apparatus (ART22)
PO7942	15-Jul-97	Image Processing Method and Apparatus (ART23)
PO8018	15-Jul-97	Image Processing Method and Apparatus (ART24)
PO7938	15-Jul-97	Image Processing Method and Apparatus (ART25)
PO8016	15-Jul-97	Image Processing Method and Apparatus (ART26)

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Australian Provisional Number	Filing Date	Title
PO8024	15-Jul-97	Image Processing Method and Apparatus (ART27)
PO7940	15-Jul-97	Data Processing Method and Apparatus (ART28)
PO7939	15-Jul-97	Data Processing Method and Apparatus (ART29)
PO8501	11-Aug-97	Image Processing Method and Apparatus (ART30)
PO8500	11-Aug-97	Image Processing Method and Apparatus (ART31)
PO7987	15-Jul-97	Data Processing Method and Apparatus (ART32)
PO8022	15-Jul-97	Image Processing Method and Apparatus (ART33)
PO8497	11-Aug-97	Image Processing Method and Apparatus (ART30)
PO8029	15-Jul-97	Sensor Creation Method and Apparatus (ART36)
PO7985	15-Jul-97	Data Processing Method and Apparatus (ART37)
PO8020	15-Jul-97	Data Processing Method and Apparatus (ART38)
PO8023	15-Jul-97	Data Processing Method and Apparatus (ART39)
PO9395	23-Sep-97	Data Processing Method and Apparatus (ART4)
PO8021	15-Jul-97	Data Processing Method and Apparatus (ART40)
PO8504	11-Aug-97	Image Processing Method and Apparatus (ART42)
PO8000	15-Jul-97	Data Processing Method and Apparatus (ART43)
PO7977	15-Jul-97	Data Processing Method and Apparatus (ART44)
PO7934	15-Jul-97	Data Processing Method and Apparatus (ART45)
PO7990	15-Jul-97	Data Processing Method and Apparatus (ART46)
PO8499	11-Aug-97	Image Processing Method and Apparatus (ART47)
PO8502	11-Aug-97	Image Processing Method and Apparatus (ART48)
PO7981	15-Jul-97	Data Processing Method and Apparatus (ART50)
PO7986	15-Jul-97	Data Processing Method and Apparatus (ART51)
PO7983	15-Jul-97	Data Processing Method and Apparatus (ART52)
PO8026	15-Jul-97	Image Processing Method and Apparatus (ART53)
PO8027	15-Jul-97	Image Processing Method and Apparatus (ART54)
PO8028	15-Jul-97	Image Processing Method and Apparatus (ART56)
PO9394	23-Sep-97	Image Processing Method and Apparatus (ART57)
PO9396	23-Sep-97	Data Processing Method and Apparatus (ART58)
PO9397	23-Sep-97	Data Processing Method and Apparatus (ART59)
PO9398	23-Sep-97	Data Processing Method and Apparatus (ART60)
PO9399	23-Sep-97	Data Processing Method and Apparatus (ART61)
PO9400	23-Sep-97	Data Processing Method and Apparatus (ART62)
PO9401	23-Sep-97	Data Processing Method and Apparatus (ART63)
PO9402	23-Sep-97	Data Processing Method and Apparatus (ART64)
PO9403	23-Sep-97	Data Processing Method and Apparatus (ART65)
PO9405	23-Sep-97	Data Processing Method and Apparatus (ART66)

(continued)

Australian Provisional Number	Filing Date	Title
PP0959	16-Dec-97	A Data Processing Method and Apparatus (ART68)
PP1397	19-Jan-98	A Media Device (ART69)

[0106] It would be appreciated by a person skilled in the art that numerous variations and/or modifications may be made to the present invention as shown in the specific embodiment without departing from the spirit or scope of the invention as broadly described. The present embodiment is, therefore, to be considered in all respects to be illustrative and not restrictive.

Claims

1. An ink jet printing nozzle arrangement comprising:

a) a plunger;
b) an electric coil located adjacent to the plunger and electrically connected to a nozzle activation signal wherein upon activation of the activation signal, said plunger is caused by said coil to move from an ink loaded position to an ink ejection position thereby causing the ejection of ink from an ink ejection port, **characterised in that** the arrangement further comprises:

i) a nozzle chamber having the ink ejection port at one end; and,
ii) an ink chamber for allowing for the supply of ink to said nozzle chamber, the plunger being constructed from soft magnetic material and being positioned between the nozzle chamber and the ink chamber.

2. An ink ejection nozzle arrangement according to claim 1, the nozzle arrangement further comprising an armature plate constructed from soft magnetic material and wherein said plunger is attracted to said armature plate on the activation of said coil.

3. An ink jet printing nozzle arrangement according to claim 1 or claim 2, wherein said electric coil is located within a cavity defined by said plunger and wherein said cavity has its dimensions reduced as a result of movement of said plunger, said plunger further having a series of fluid release slots in fluid communication with said cavity and said ink chamber, said fluid release slots allowing for the expulsion of fluid under pressure in said cavity.

4. An ink jet printing nozzle according to claim 3, wherein said slots are defined around an inner circumference of said coil and said slots have a substantially constant cross-sectional profile.

5. An ink jet printing nozzle according to claim 4, wherein said slots are located in a radial manner on one surface of said plunger.

6. An ink jet printing nozzle arrangement according to any of claims 1 to 5, the nozzle arrangement further comprising a resilient means for assisting in the return of said plunger from said ink ejection position to said ink loaded position after the ejection of ink from said ink ejection port.

7. An ink jet printing nozzle arrangement according to claim 6, wherein said resilient means comprises a torsional spring.

8. An ink jet printing nozzle arrangement according to claim 7, wherein said torsional spring is of an arcuate construction having a circumferential profile substantially the same as that of said plunger.

9. An ink jet printing nozzle apparatus according to any one of the claims 6 to 8, the resilient means being adapted to return said magnetic plunger to said first position upon deactivation of said activation coil.

10. An ink jet printing nozzle apparatus according to any of claims 6 to 9, wherein said resilient means constructed from silicon nitride.

11. An ink jet printing nozzle apparatus according to any of claims 1 to 10, wherein said apparatus is constructed utilizing semi-conductor fabrication techniques.

12. An ink jet printing nozzle apparatus according to claim 11, wherein said plunger and/or, said coils are constructed from a dual damascene process.

13. An inkjet printing nozzle apparatus according to any of claims 1 to 12, wherein said ink ejection port includes a nozzle rim adapted to reduce hydrophilic surface spreading of said ink.

14. An ink jet printing nozzle apparatus according to any of claims 1 to 13, wherein said activation coil is constructed from a copper deposition process.

15. An ink jet nozzle arrangement according to claim 1, wherein said plunger is substantially circular and has a tapered rim adjacent portions of said electromagnetic device.

16. An ink jet nozzle arrangement according to claim 1 or claim 15, wherein said electromagnetic device is of a torus shape and said plunger is located in the center of said torus.

17. An ink jet nozzle arrangement according to claim 15 or claim 16, wherein said plunger is further connected to a resilient means which allows for the return of said plunger to its original position upon deactivation of said electromagnetic device.

18. An ink jet nozzle arrangement according to claim 17, wherein said resilient means is a series of springs.

19. An ink jet nozzle arrangement according to claim 18, wherein said springs are interconnedcted to a central portion of said plunger and radially spiral out to said side walls.

20. An ink jet nozzle arrangement according to claim 17 or claim 18, wherein said springs are formed from tensional release of deposited material.

21. An ink jet nozzle arrangement according to claim 20, wherein said deposited material includes nitride.

Patentansprüche

1. Tintenstrahldruckdüsenanordnung, umfassend

a) einen Tauchkern;

b) eine elektrische Spule, die angrenzend an den Tauchkern angeordnet und elektrisch mit einem Düsenaktivierungssignal verbunden ist, worin nach Aktivierung des Aktivierungssignals der Tauchkern von der Spule veranlasst wird, sich von einer mit Tinte gefüllten Position zu einer Tintenausstoßposition zu bewegen, wodurch das Ausstoßen von Tinte von einer Tintenausstoßöffnung verursacht wird, **dadurch gekennzeichnet, dass** die Anordnung weiters Folgendes umfasst:

i) eine Düsenkammer mit der Tintenausstoßöffnung an einem Ende; und
ii) eine Tintenkammer zur Ermöglichung der Zufuhr von Tinte zur Düsenkammer, wobei der Tauchkern aus einem weichmagnetischen Material gefertigt und zwischen der Düsenkammer und der Tintenkammer angeordnet ist.

2. Tintenausströmdüsenanordnung nach Anspruch 1, wobei die Düsenanordnung weiters einen Anker, der aus einem weichmagnetischen Material gefertigt ist, umfasst, und worin der Tauchkern bei der Aktivierung der Spule zum Anker hin gezogen wird.

3. Tintenstrahldruckdüsenanordnung nach Anspruch 1 oder Anspruch 2, worin die elektrische Spule in einem vom Tauchkern definierten Hohlraum angeordnet ist und worin die Maße des Hohlraums als Folge der Bewegung des

Tauchkerns verkleinert werden, wobei der Tauchkern weiters eine Reihe an Fluidauslassschlitzen, die in Fluidkommunikation mit dem Hohlraum und der Tintenkammer stehen, aufweist, wobei die Fluidauslassschlitze einen Ausstoß eines Fluids unter Druck im Hohlraum zulassen.

4. Tintenstrahldruckdüse nach Anspruch 3, worin die Schlitze um einen inneren Umfang der Spule herum definiert sind und die Schlitze ein im Wesentlichen konstantes Querschnittsprofil aufweisen.

5. Tintenstrahldruckdüse nach Anspruch 4, worin die Schlitze radial an einer Oberfläche des Tauchkerns angeordnet sind.

6. Tintenstrahldruckdüsenanordnung nach einem der Ansprüche 1 bis 5, wobei die Düsenanordnung weiters Federungsmittel zur Unterstützung des Tauchkerns bei der Rückkehr von der Tintenausstoßposition zur mit Tinte gefüllten Position nach dem Ausstoßen der Tinte aus der Tintenausstoßöffnung umfasst.

7. Tintenstrahldruckdüsenanordnung nach Anspruch 6, worin das Federungsmittel eine Torsionsfeder umfasst.

8. Tintenstrahldruckdüsenanordnung nach Anspruch 7, worin die Torsionsfeder gekrümmt konstruiert ist und ein im Wesentlichen gleiches Umfangsprofil wie jenes des Tauchkerns aufweist.

9. Tintenstrahldruckdüsenvorrichtung nach einem der Ansprüche 6 bis 8, wobei das Federungsmittel angepasst ist, um den magnetischen Tauchkern nach der Deaktivierung der Aktivierungsspule zur ersten Position zurückzubewegen.

10. Tintenstrahldruckdüsenvorrichtung nach einem der Ansprüche 6 bis 9, worin das Federungsmittel aus Siliciumnitrid hergestellt ist.

11. Tintenstrahldruckdüsenvorrichtung nach einem der Ansprüche 1 bis 10, worin die Vorrichtung unter Verwendung von Halbleiterfertigungstechniken hergestellt ist.

12. Tintenstrahldruckdüsenvorrichtung nach Anspruch 11, worin der Kolben und/oder die Spulen durch ein Dual-Damascene-Verfahren hergestellt sind.

13. Tintenstrahldruckdüsenvorrichtung nach einem der Ansprüche 1 bis 12, worin die Tintenausstoßöffnung einen Düsenrand umfasst, der zur Verringerung der hydrophilen Oberflächenverteilung der Tinte angepasst ist.

14. Tintenstrahldruckdüsenvorrichtung nach einem der Ansprüche 1 bis 13, worin die Aktivierungsspule durch ein Kupfer-Aufdampfverfahren hergestellt ist.

15. Tintenstrahldüsenanordnung nach Anspruch 1, worin der Tauchkern im Wesentlichen kreisförmig ist und einen konischen Rand aufweist, der an Abschnitte der elektromagnetischen Einrichtung angrenzt.

16. Tintenstrahldüsenanordnung nach Anspruch 1 oder Anspruch 15, worin die elektromagnetische Einrichtung torusförmig ist und der Tauchkern in der Mitte des Torus angeordnet ist.

17. Tintenstrahldüsenanordnung nach Anspruch 15 oder Anspruch 16, worin der Tauchkern weiters mit einem Federungsmittel verbunden ist, das die Rückkehr des Tauchkerns nach der Deaktivierung der Aktivierungsspule zur Ausgangsposition zulässt.

18. Tintenstrahldüsenanordnung nach Anspruch 17, worin das Federungsmittel eine Reihe von Federn ist.

19. Tintenstrahldüsenanordnung nach Anspruch 18, worin die Federn mit einem zentralen Abschnitt des Tauchkerns verbunden sind und radial in Spiralform zu den Seitenwänden hin verlaufen.

20. Tintenstrahldüsenanordnung nach Anspruch 17 oder Anspruch 18, worin die Federn durch Spannungsentlastung von aufgedampftem Material gebildet sind.

21. Tintenstrahldüsenanordnung nach Anspruch 20, worin das aufgedampfte Material Nitrid umfasst.

Revendications

1. Agencement de buse d'impression à jet d'encre comprenant:

a) un plongeur;
b) une bobine électrique située d'une manière adjacente au plongeur et reliée électriquement à un signal d'activation de buse, dans lequel, lors de l'activation du signal d'activation, ledit plongeur est amené par ladite bobine à passer d'une position chargée en encre à une position d'éjection d'encre en provoquant ainsi l'éjection de l'encre d'un orifice d'éjection d'encre, **caractérisé en ce que** l'agencement comprend en outre:

i) une chambre de buse comportant un orifice d'éjection d'encre à une extrémité; et,
ii) une chambre d'encre permettant l'amenée de l'encre à ladite chambre de buse, le plongeur étant construit en un matériau magnétique mou et étant positionné entre la chambre de buse et la chambre d'encre.

2. Agencement de buse d'éjection d'encre selon la revendication 1, l'agencement de buse comprenant en outre une plaque d'induit réalisée en un matériau magnétique mou, et où ledit plongeur est attiré vers ladite plaque d'induit lors de l'activation de ladite bobine.

3. Agencement de buse d'impression à jet d'encre selon la revendication 1 ou la revendication 2, où ladite bobine électrique se situe dans une cavité définie par ledit plongeur, et où ladite cavité a ses dimensions réduites par suite du mouvement dudit plongeur, ledit plongeur comportant en outre une série de fentes de libération de fluide en communication fluidique avec ladite cavité et ladite chambre d'encre, lesdites fentes de libération de fluide permettant l'expulsion du fluide sous pression dans ladite cavité.

4. Buse d'impression à jet d'encre selon la revendication 3, où lesdites fentes sont définies autour d'une circonférence interne de ladite bobine, et lesdites fentes ont un profil en sect ion transversale sensiblement constant.

5. Buse d'impression à jet d'encre selon la revendication 4, où lesdites fentes se situent d'une manière radiale sur une surface dudit plongeur.

6. Agencement de buse d'impression à jet d'encre selon l'une des reve ndications 1 à 5, l'arrangement de buse comprenant en outre un moyen élastique pour contribuer au retour dudit plongeur de ladite position d'éjection d'encre à ladite position chargée en encre après l'éjection de l'encre depuis ledit orifice d'éjection d'encre.

7. Agencement de buse d'impression à jet d'encre selon la revendication 6, où ledit moyen élastique comprend un ressort de torsion.

8. Agencement de buse d'impression à jet d'encre selon la revendication 7, où ledit ressort de torsion est d'une construction arquée ayant un profil circonférentiel qui est sensiblement le même que celui dudit plongeur.

9. Appareil à buse d'impression à jet d'encre selon l'une des revendications 6 à 8, le moyen élastique étant apte à ramener ledit plongeur magnétique à ladite première position lors de la désactivation de ladite bobine d'activation.

10. Appareil à buse d'impression à jet d'encre selon l'une des revendications 6 à 9, où ledit moyen élastique est réalisé en nitrure de silicium.

11. Appareil à buse d'impression à jet d'encre selon l'une des revendications 1 à 10, où ledit appareil est construit en utilisant des techniques de fabrication de semi-conducteur.

12. Appareil à buse d'impression à jet d'encre selon la revendication 11, où ledit plongeur et/ou lesdites bobines sont construites par un processus de damascène double.

13. Appareil à buse d'impression à jet d'encre selon l'une des revendications 1 à 12, où ledit orifice d'éjection d'encre comporte un bord de buse apte à réduire l'étalement de surface hydrophile de ladite encre.

14. Appareil à buse d'impression à jet d'encre selon l'une des revendications 1 à 13, où ladite bobine d'activation est construite par un processus de dépôt de cuivre.

15. Agencement de buse à jet d'encre selon la revendication 1, où ledit plongeur est sensiblement circulaire et présente un bord diminué adjacent à des portions dudit dispositif électromagnétique.

16. Agencement de buse à jet d'encre selon la revendication 1 ou la revendication 15, où ledit dispositif électromagnétique est en forme de tore, et ledit plongeur se situe au centre dudit tore.

17. Agencement de buse à jet d'encre selon la revendication 15 ou la revendication 16, où ledit plongeur est relié en outre à un moyen élastique qui permet le retour dudit plo ngeur à sa position initiale lors de la désactivation dudit dispositif électromagnétique.

18. Agencement de buse à jet d'encre selon la revendication 17, où ledit moyen élastique est une série de ressorts.

19. Agencement de buse à jet d'encre selon la revendication 18, où lesdits ressorts sont interconnectés à une portion centrale dudit plongeur et s'étendent en spirale radialement vers lesdites parois latérales.

20. Agencement de buse à jet d'encre selon la revendication 17 ou la revendication 18, où lesdits ressorts sont réalisés par un relâchement de tension de matériau déposé.

21. Agencement de buse à jet d'encre selon la revendication 20, où ledit matériau déposé comprend du nitrure.

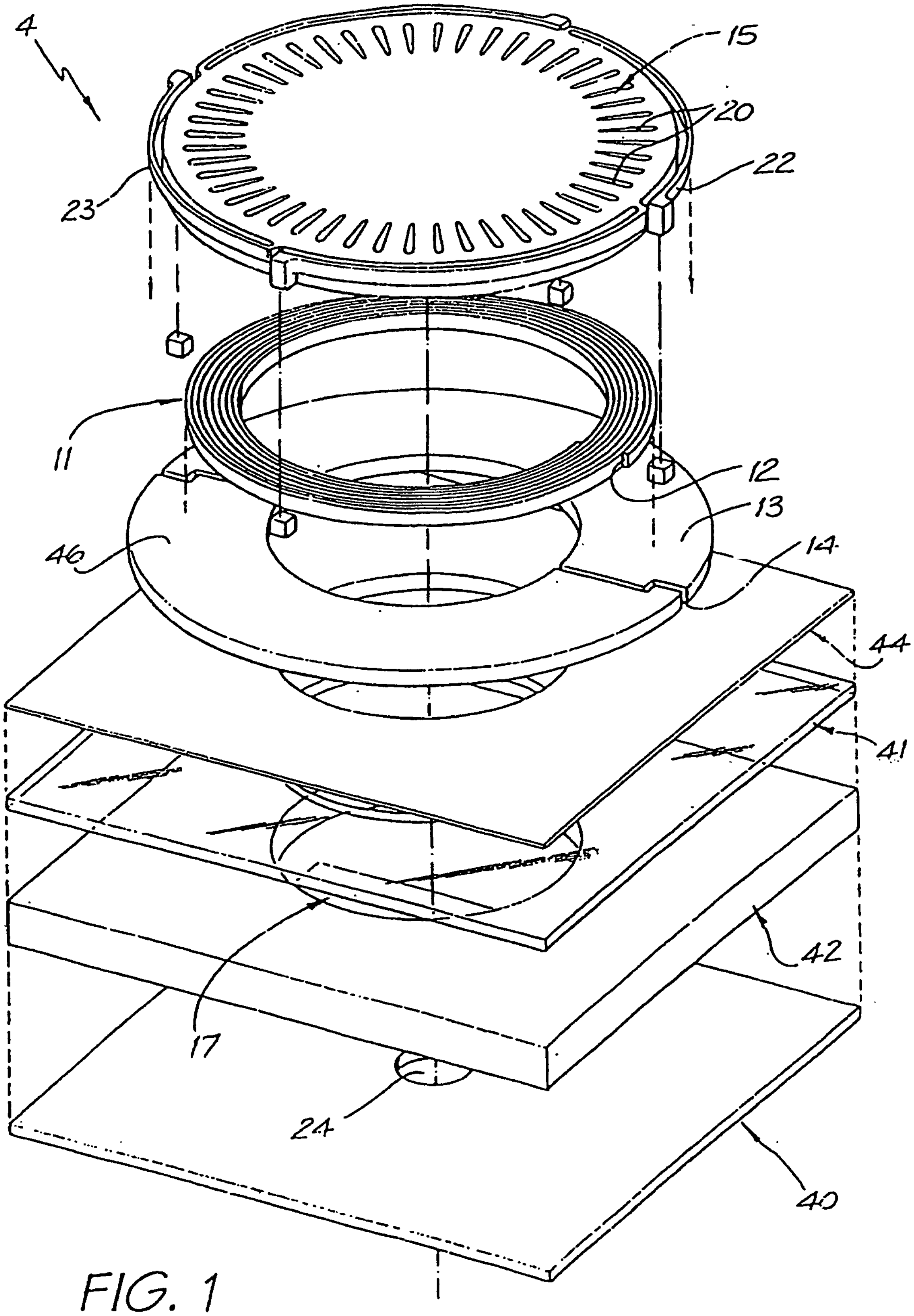


FIG. 1

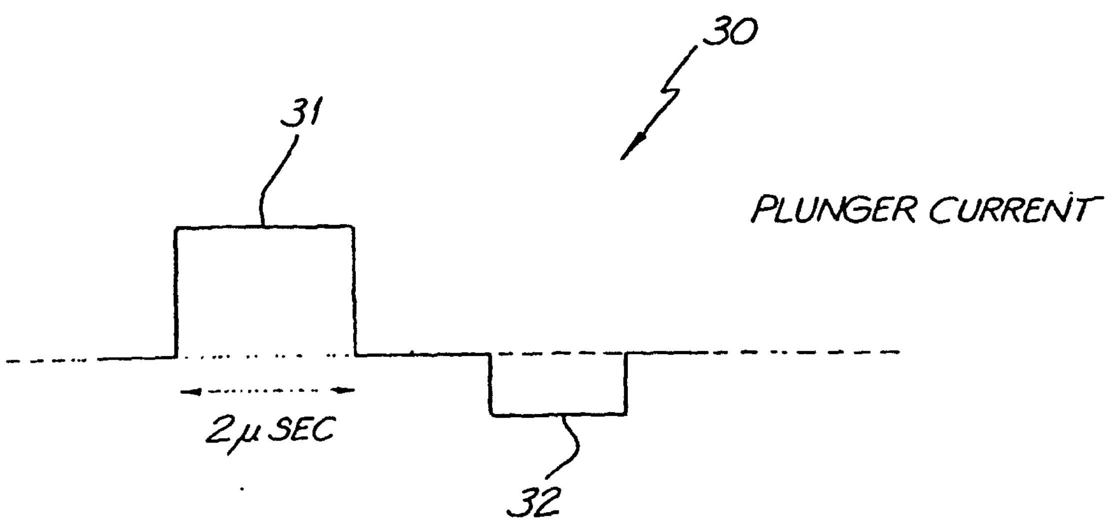


FIG. 2

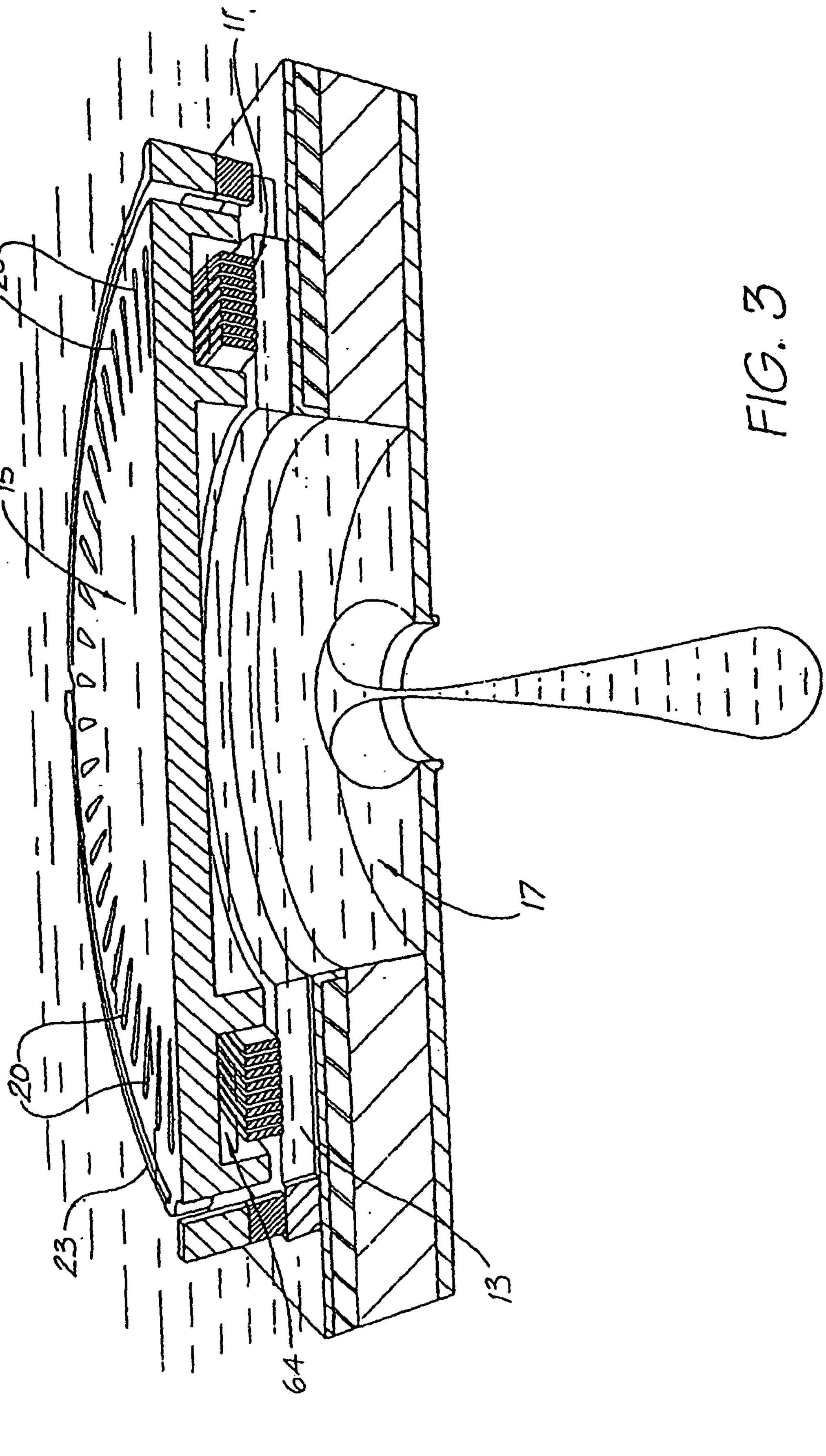


FIG. 3

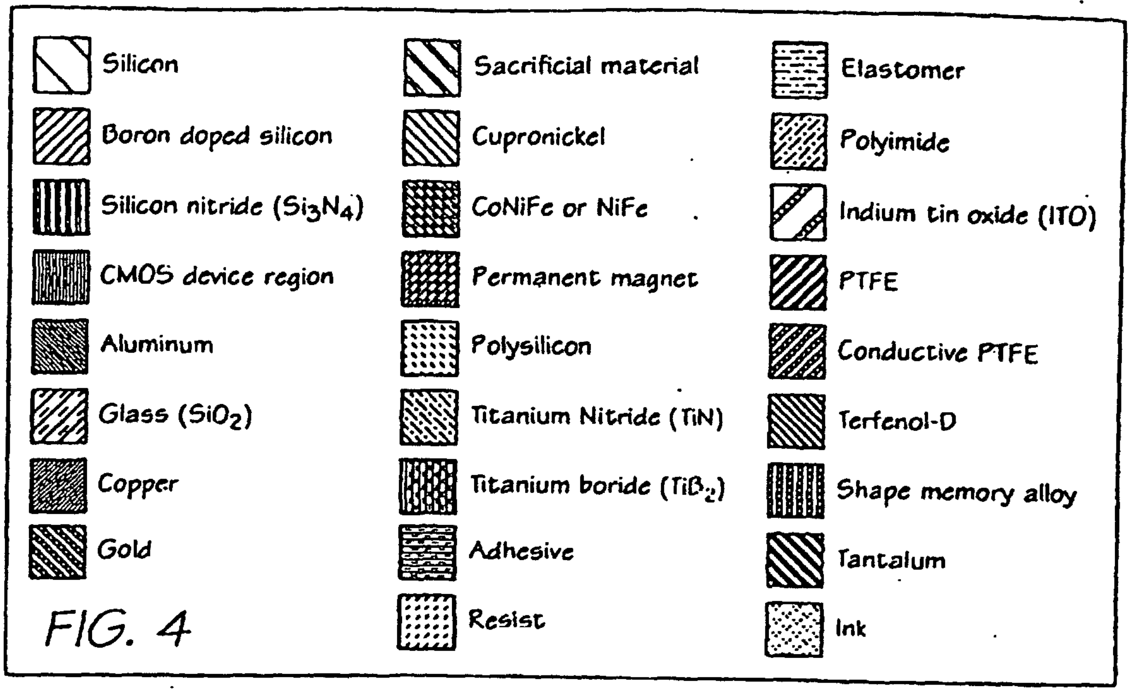


FIG. 4

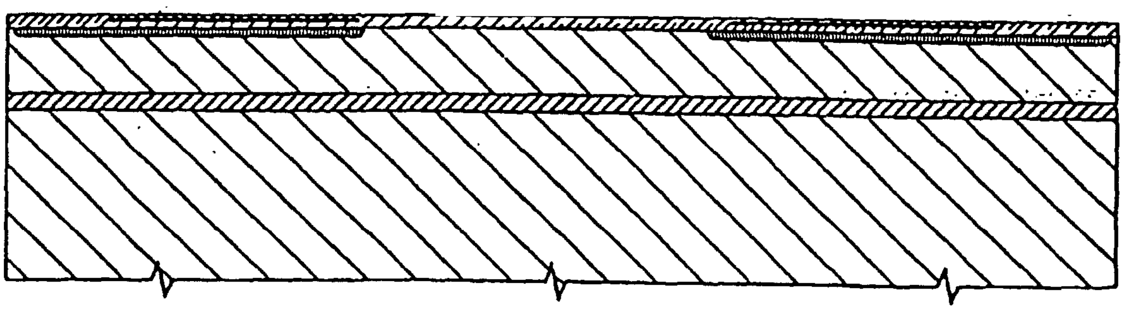


FIG. 5

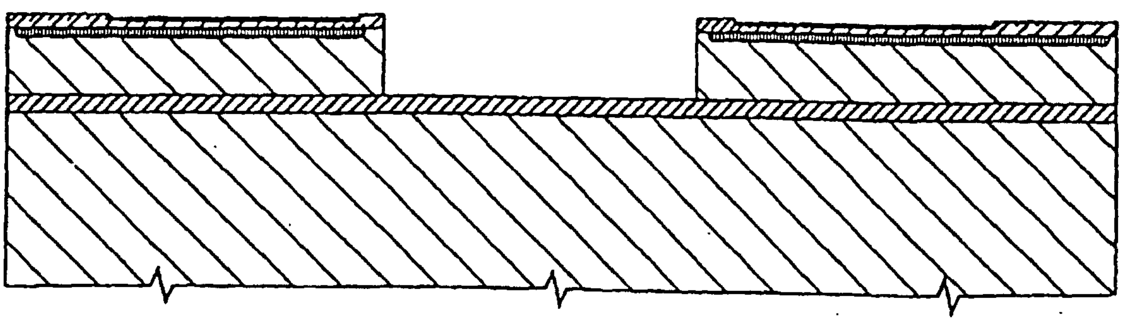


FIG. 6

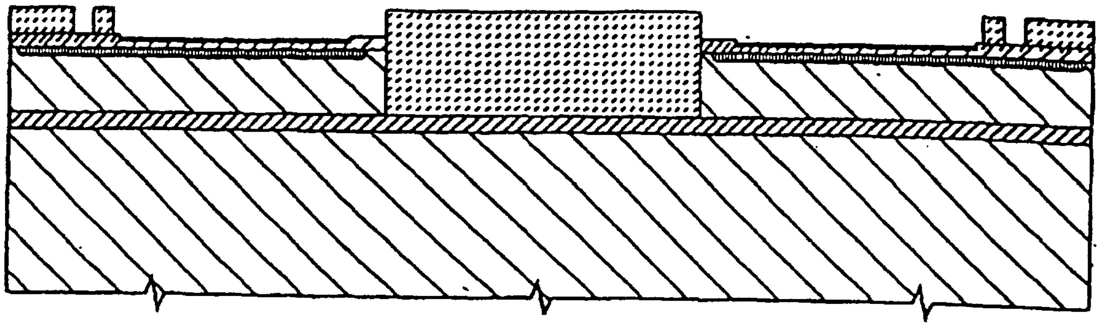


FIG. 7

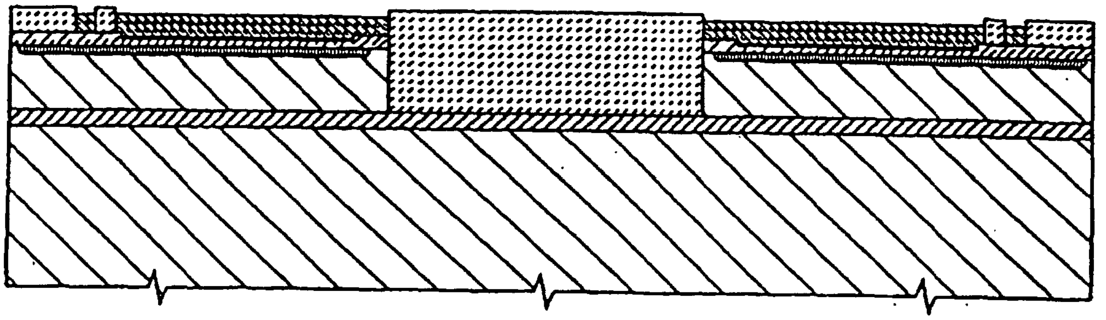


FIG. 8

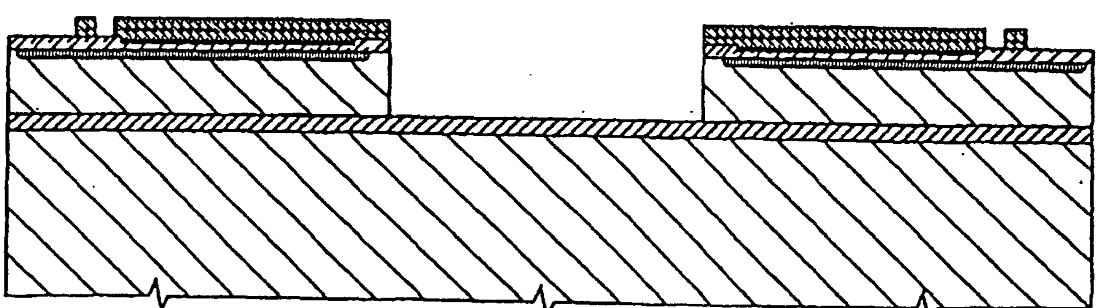


FIG. 9

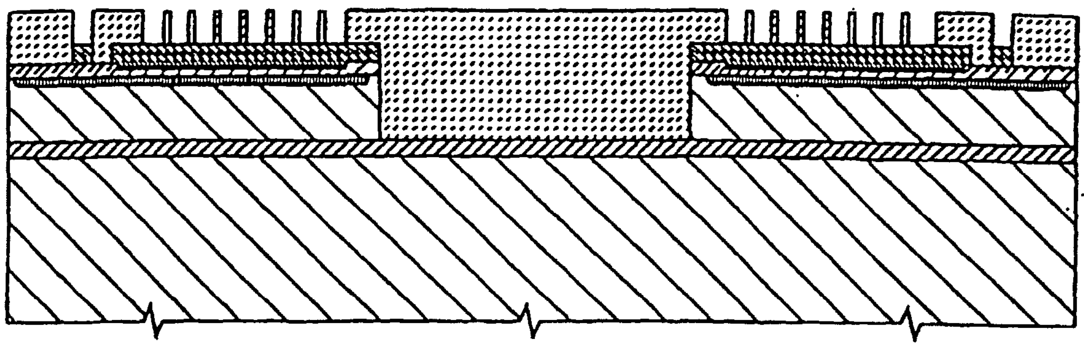


FIG. 10

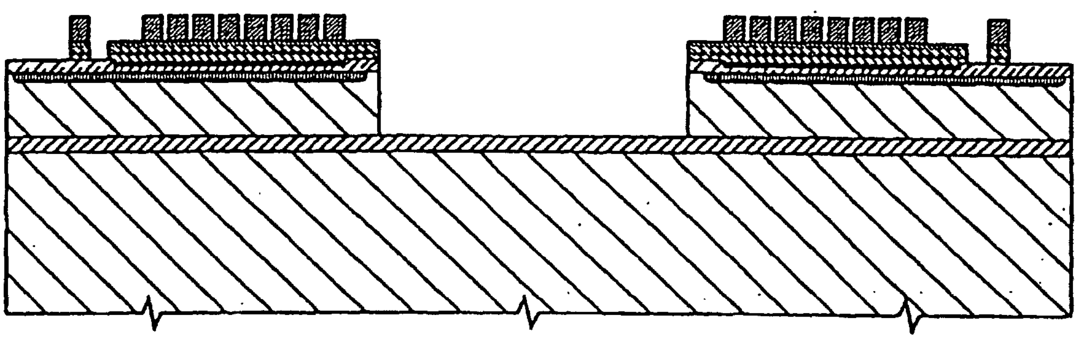


FIG. 11

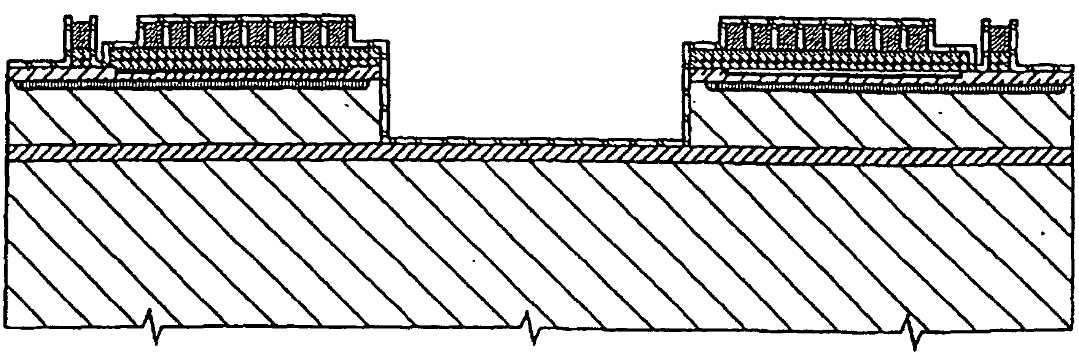


FIG. 12

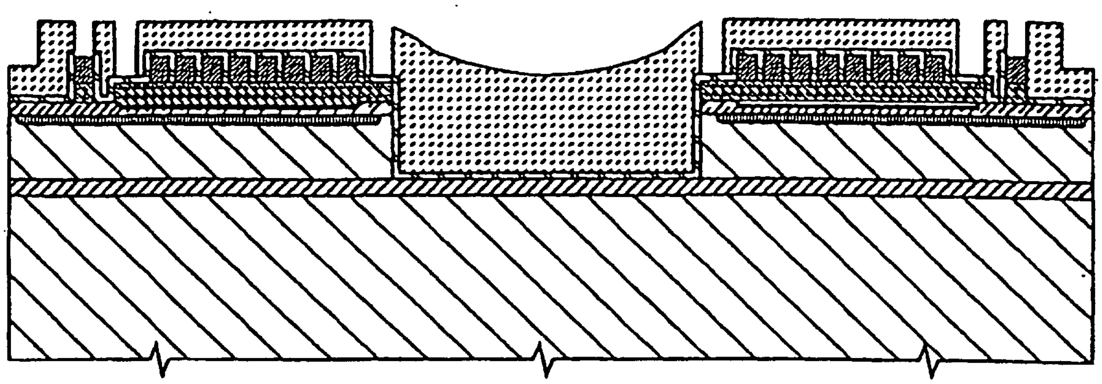


FIG. 13

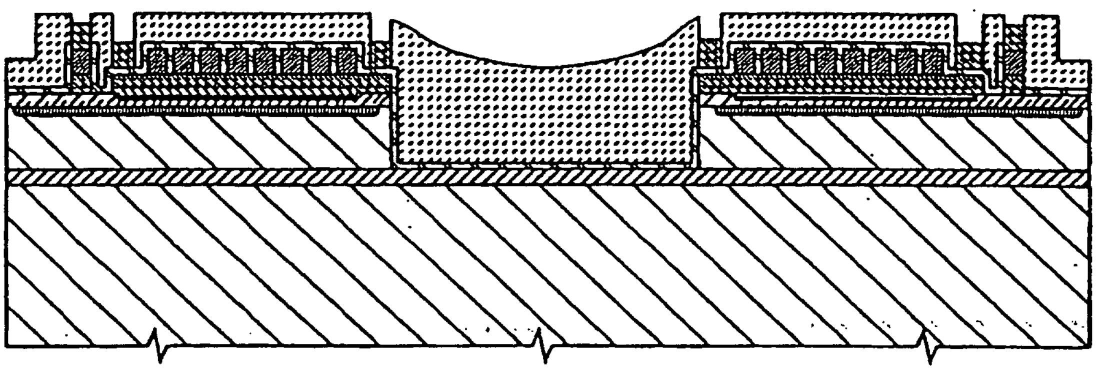


FIG. 14

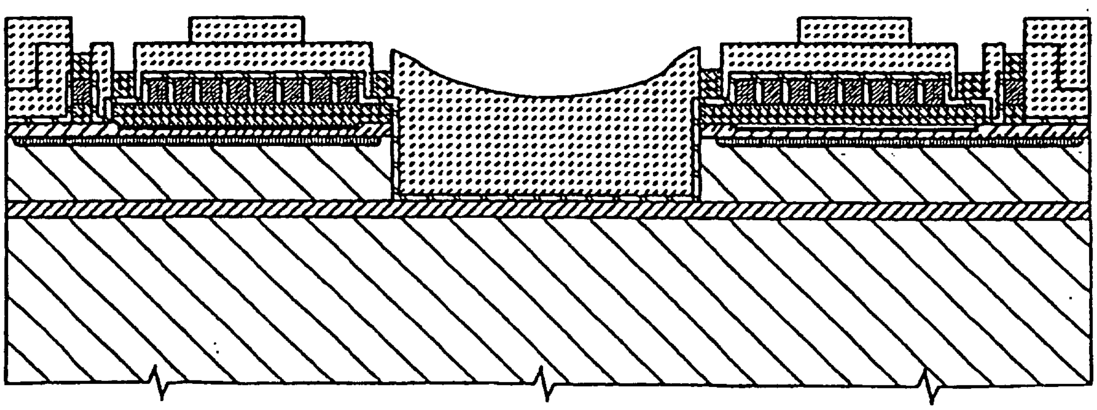


FIG. 15

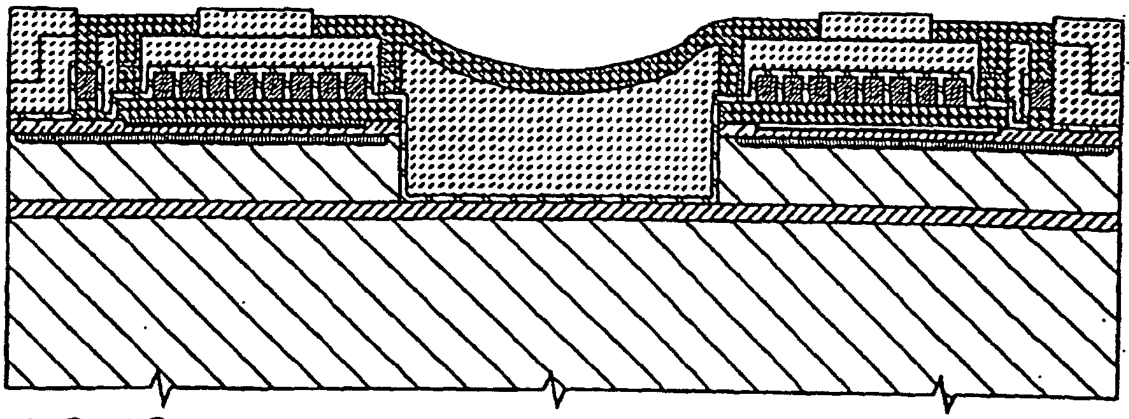


FIG. 16

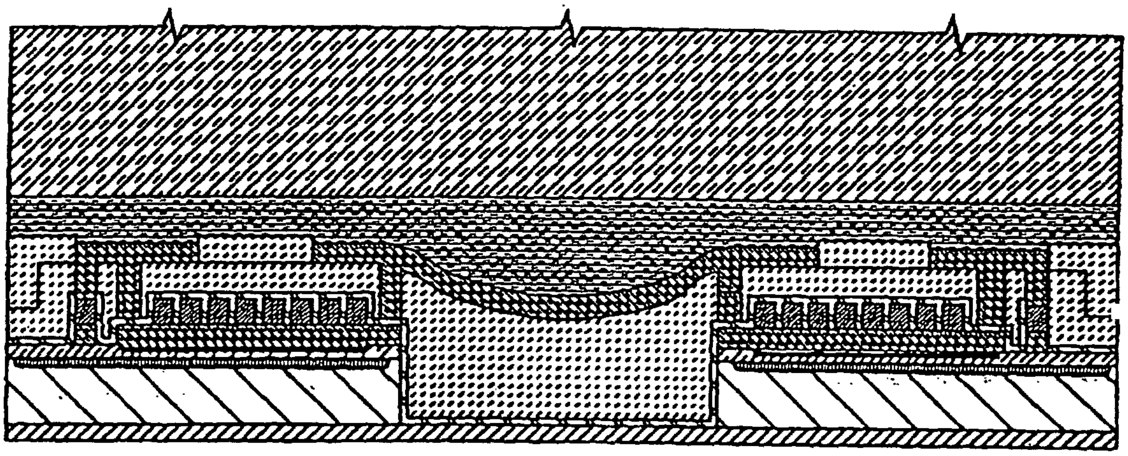
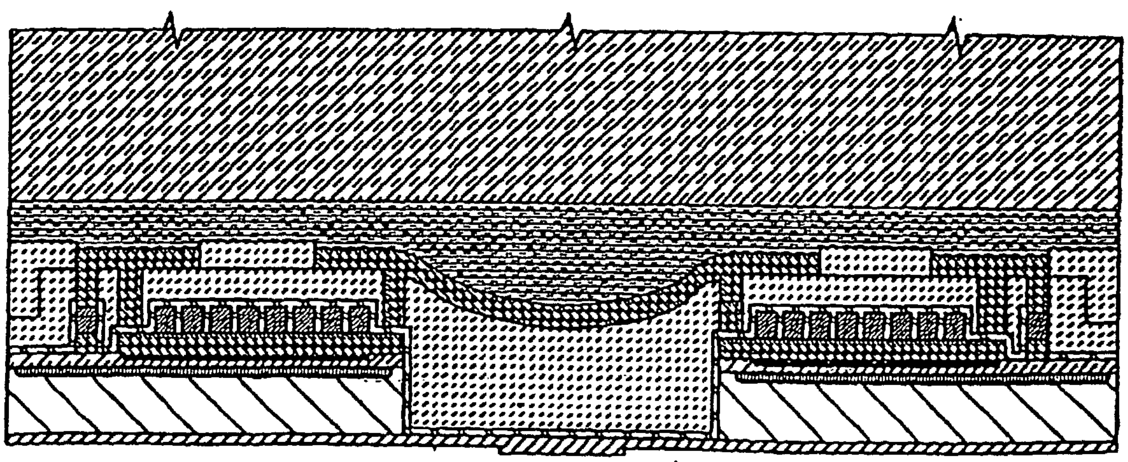


FIG. 17



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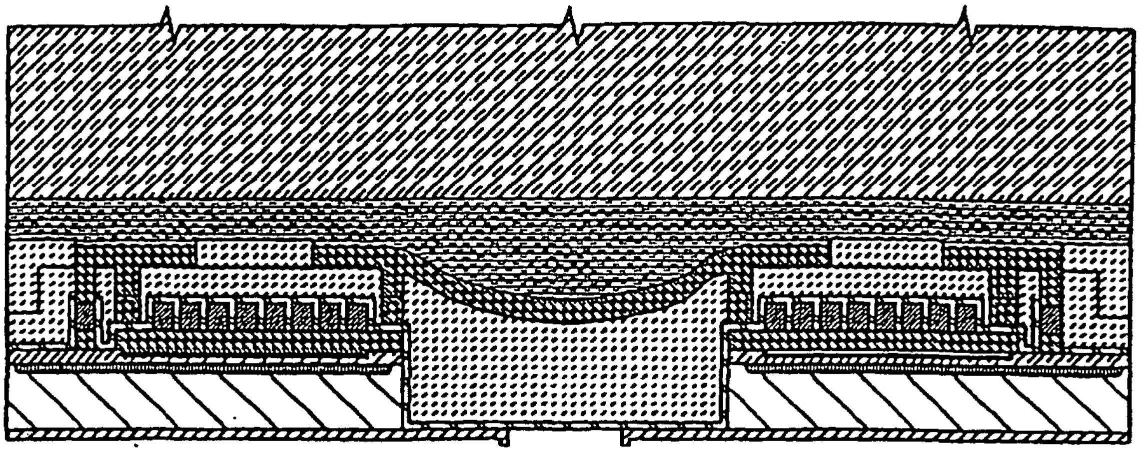

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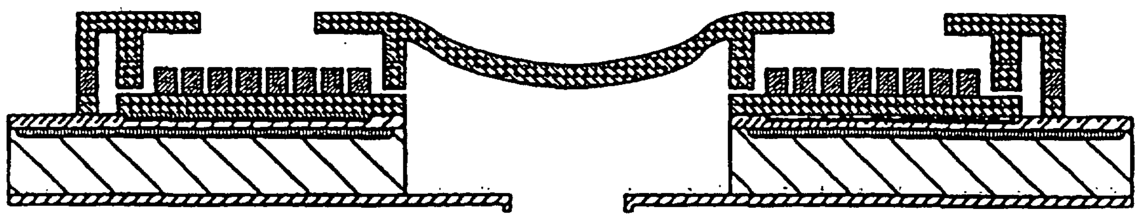

FIG. 20

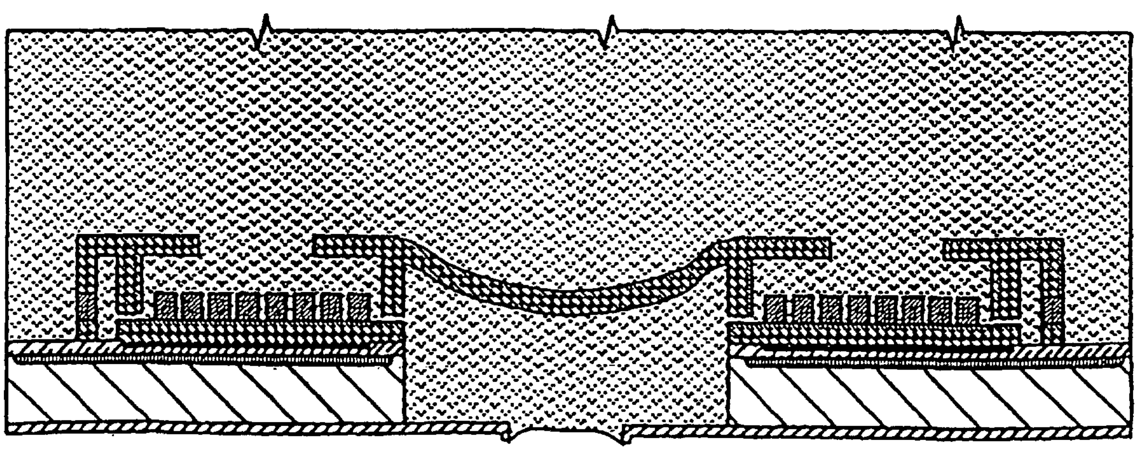

FIG. 21

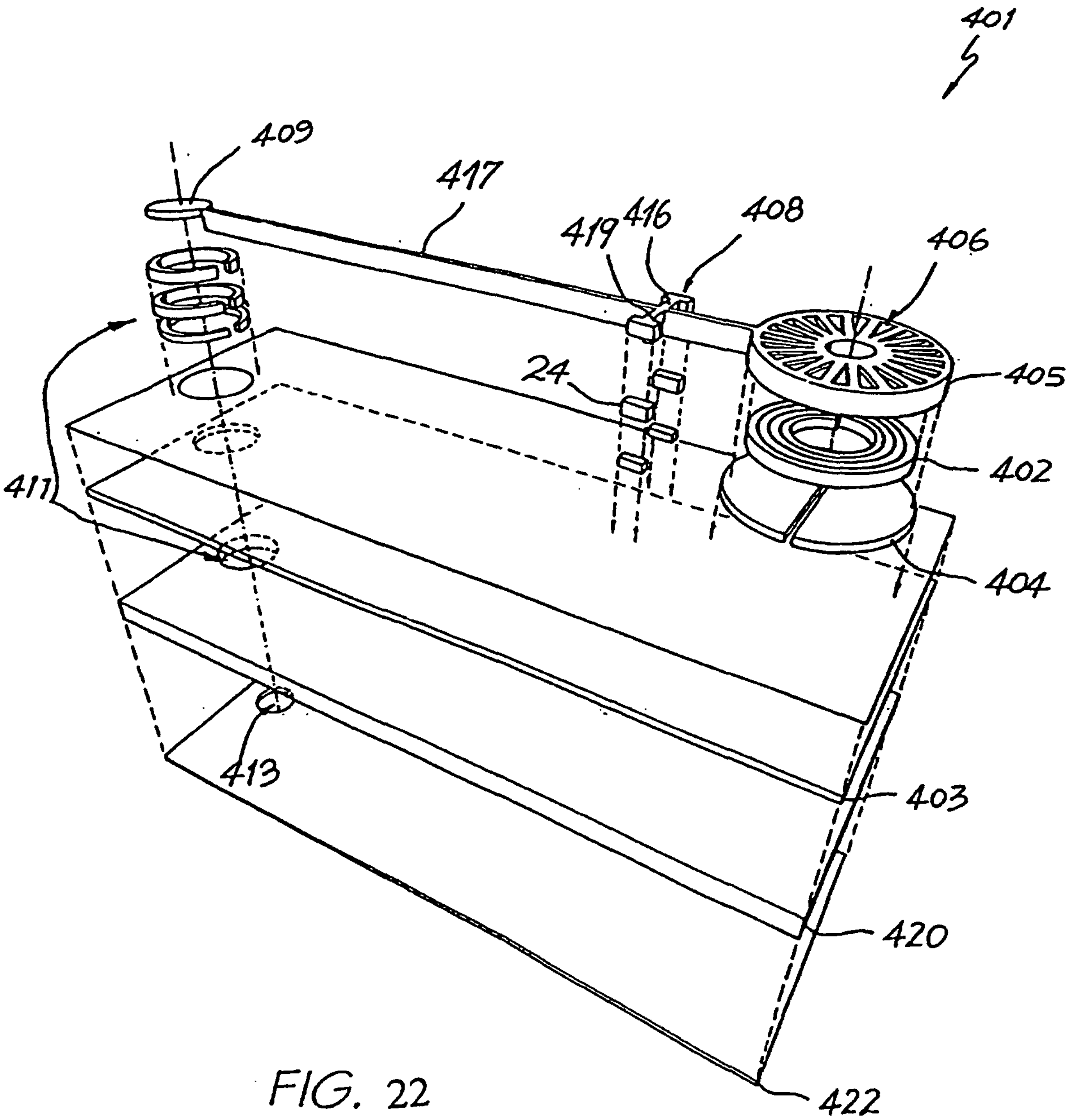

FIG. 22

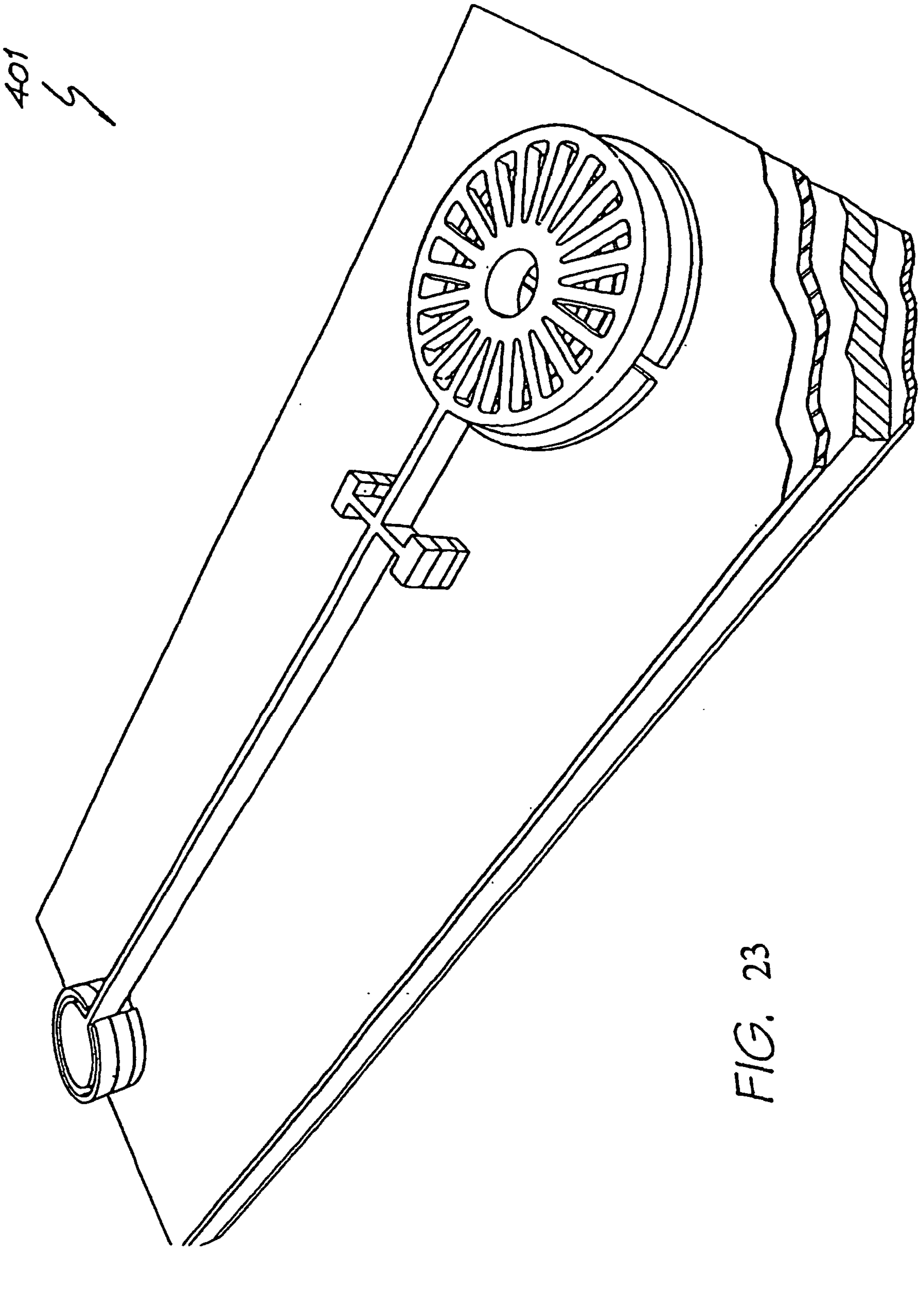

FIG. 23

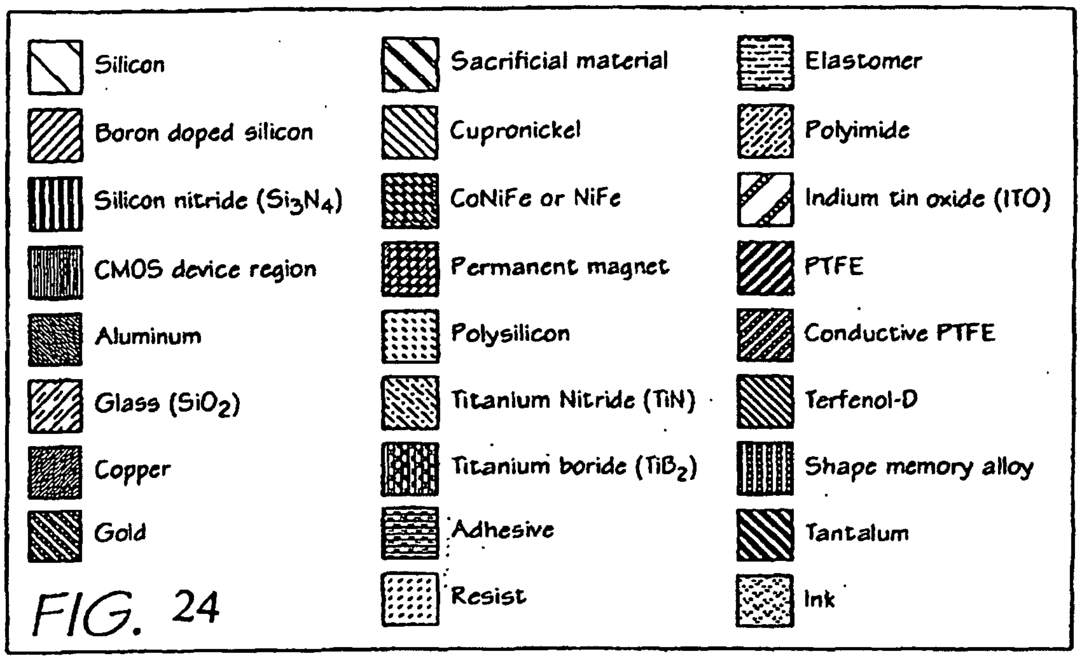

FIG. 24

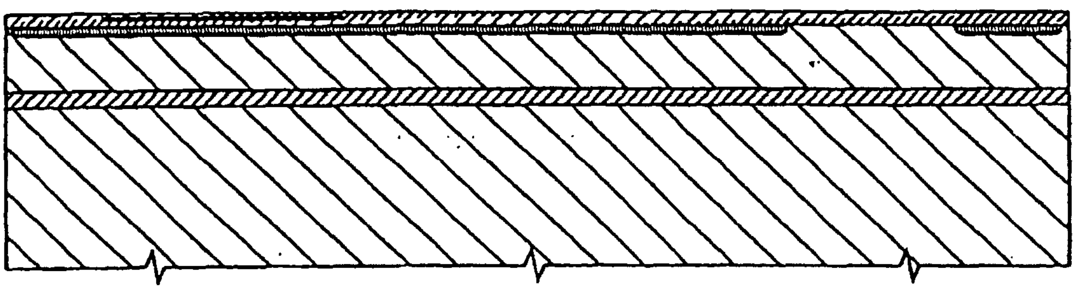

FIG. 25

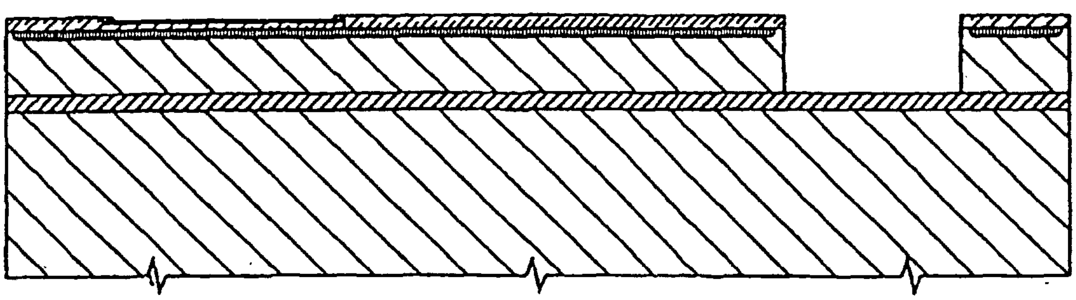

FIG. 26

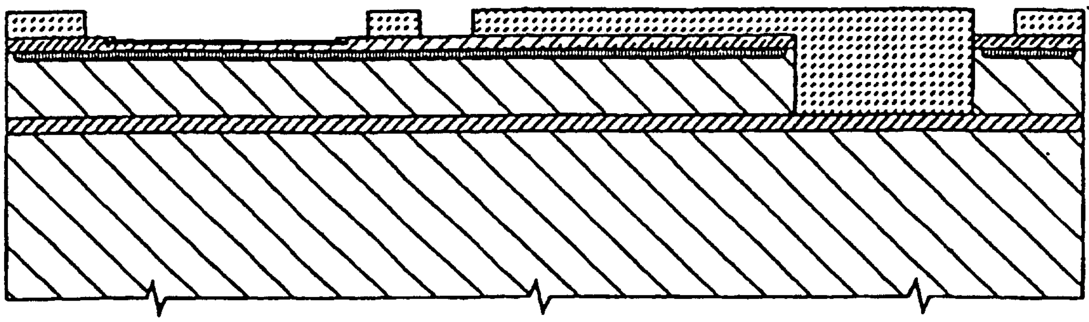

FIG. 27

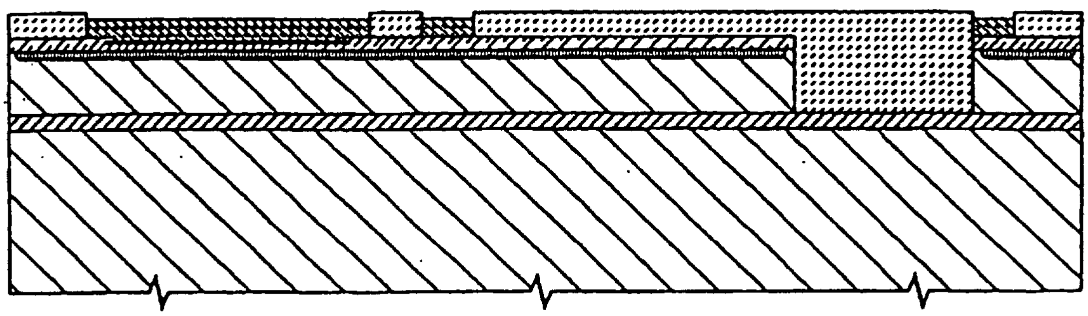

FIG. 28

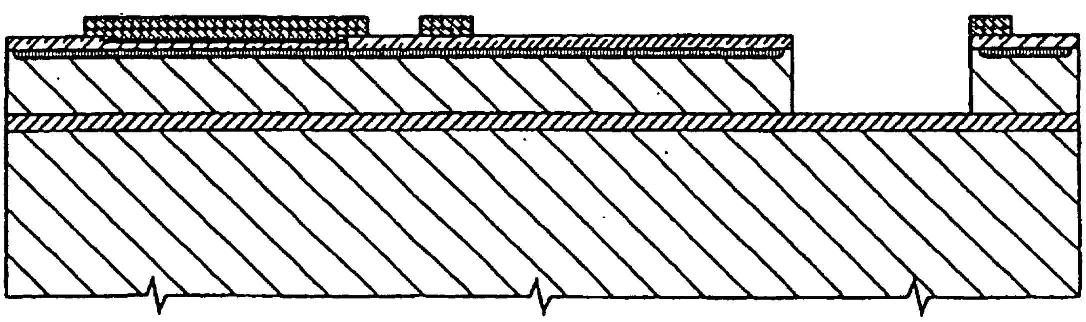

FIG. 29

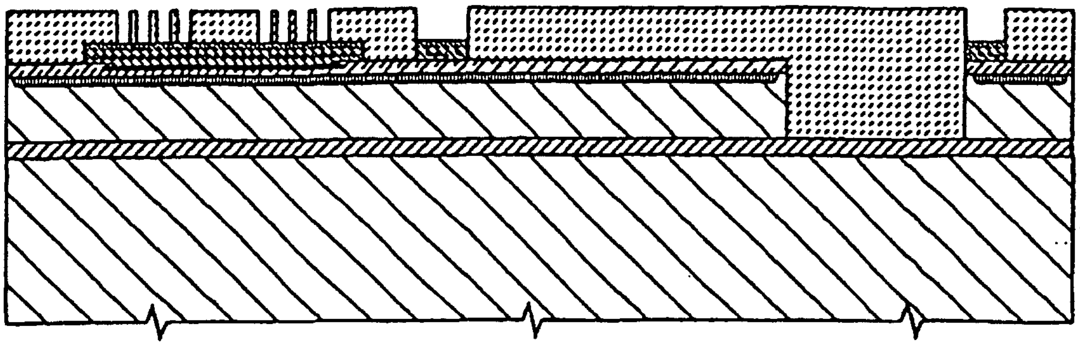

FIG. 30

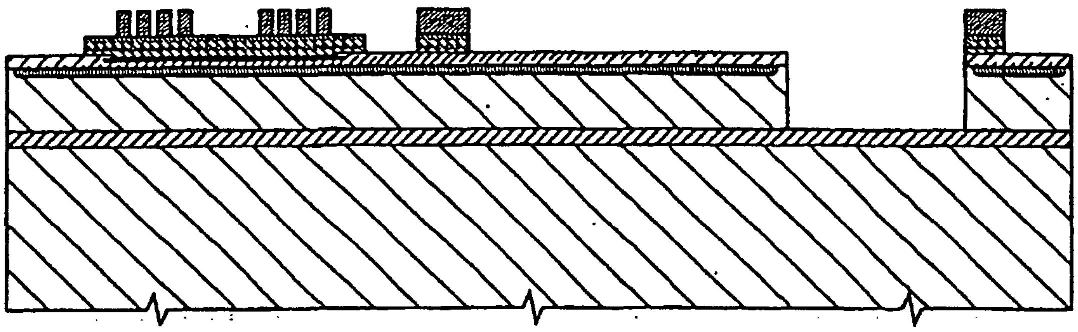

FIG. 31

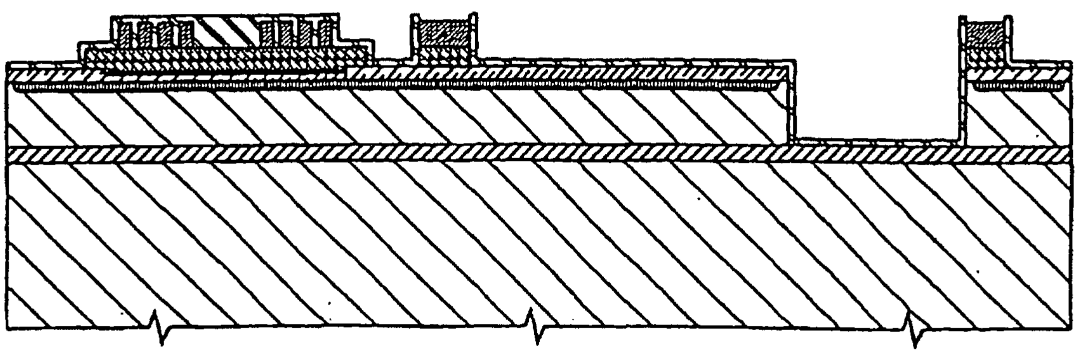

FIG. 32

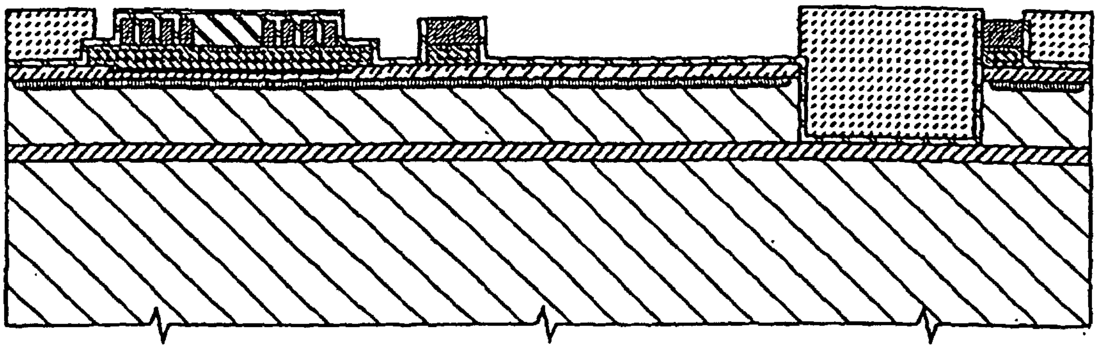

FIG. 33

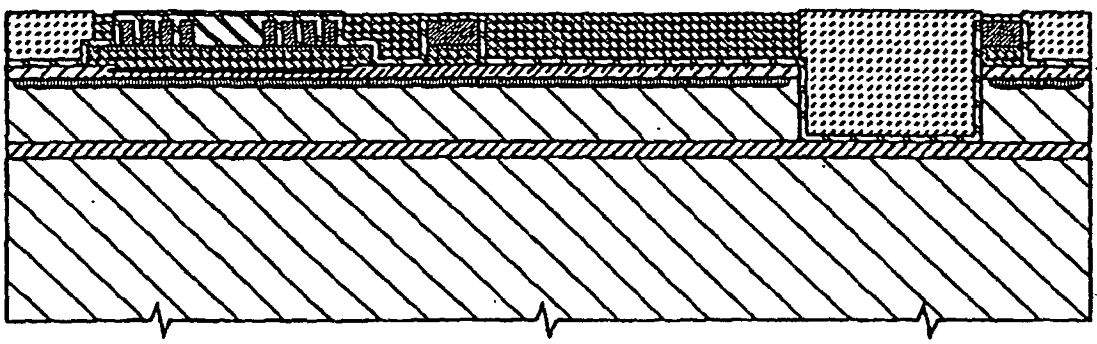

FIG. 34

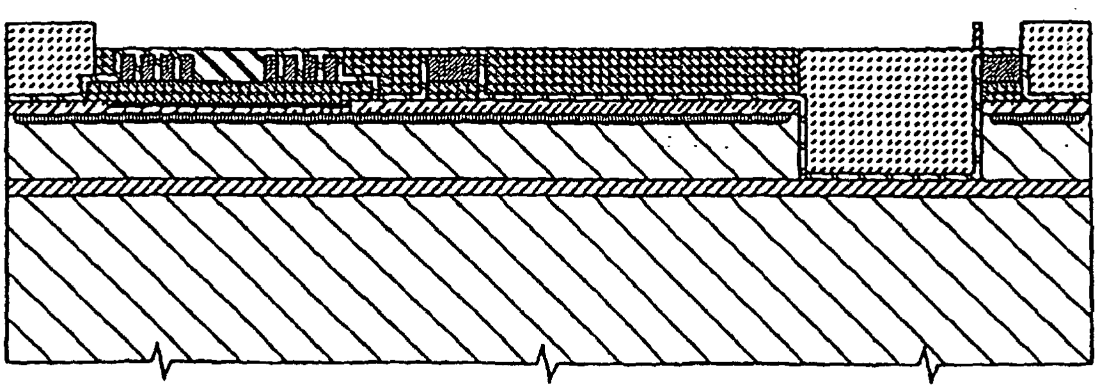

FIG. 35

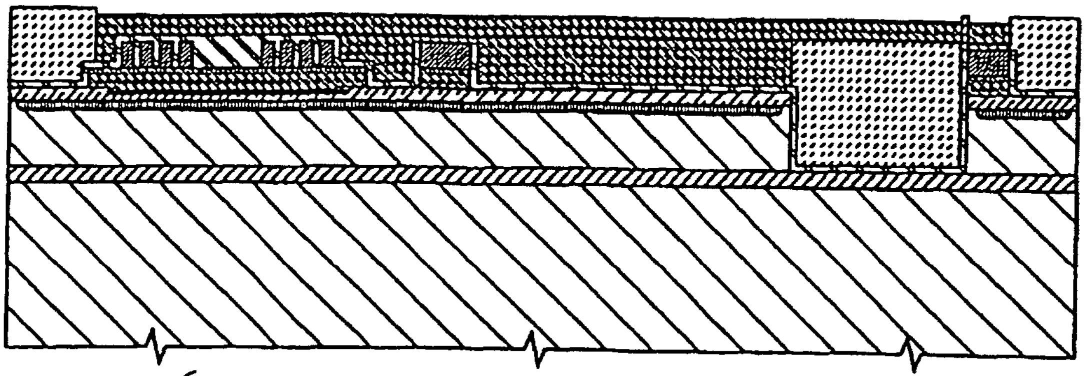

FIG. 36

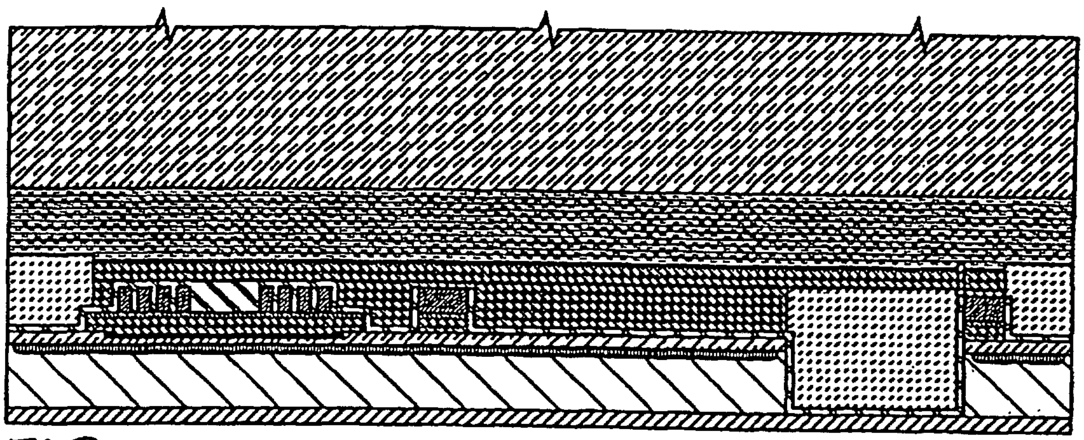

FIG. 37

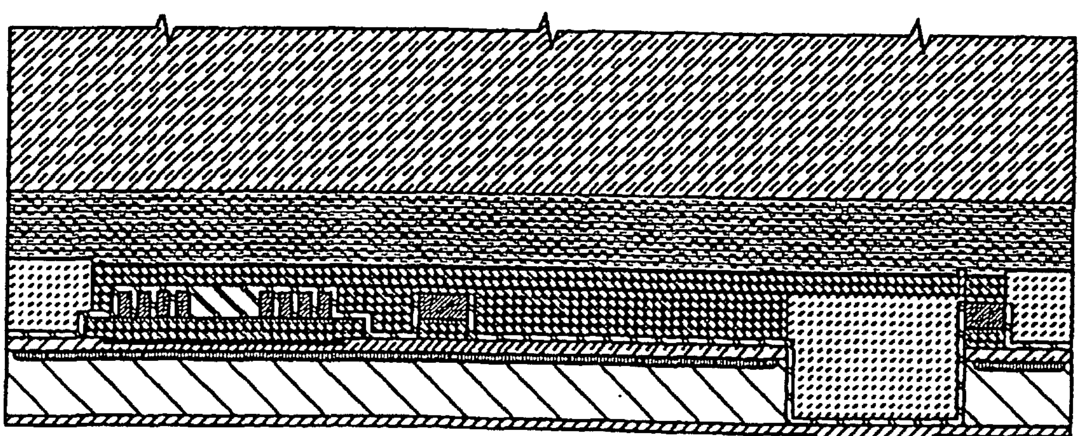

FIG. 38

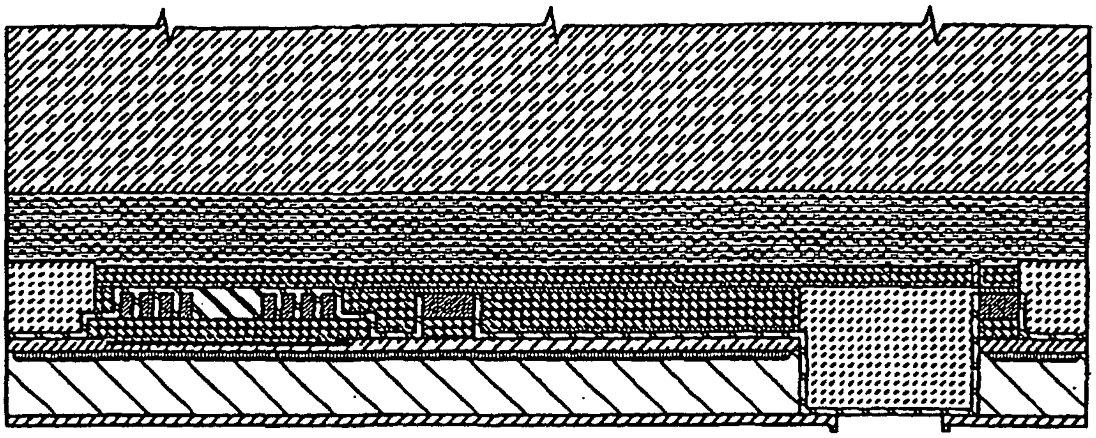

FIG. 39

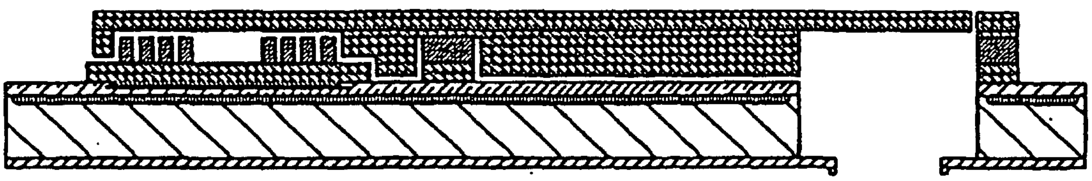

FIG. 40

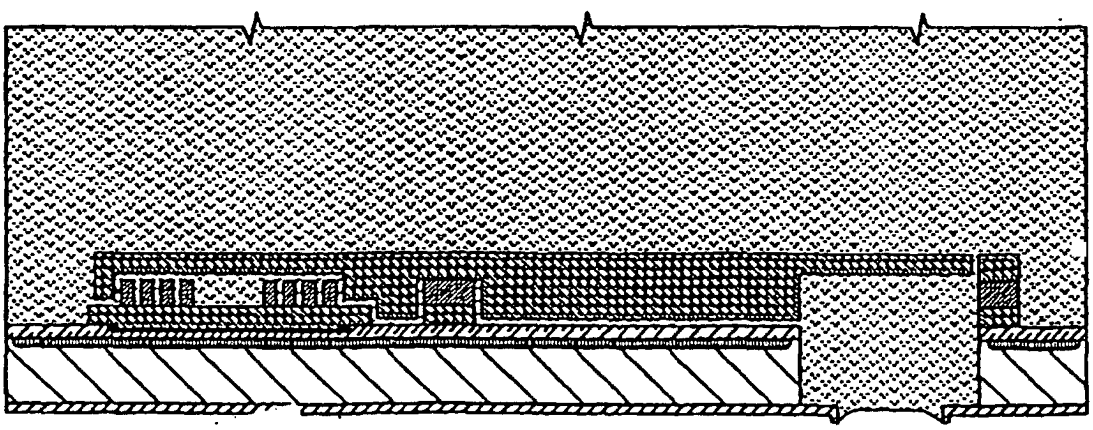

FIG. 41

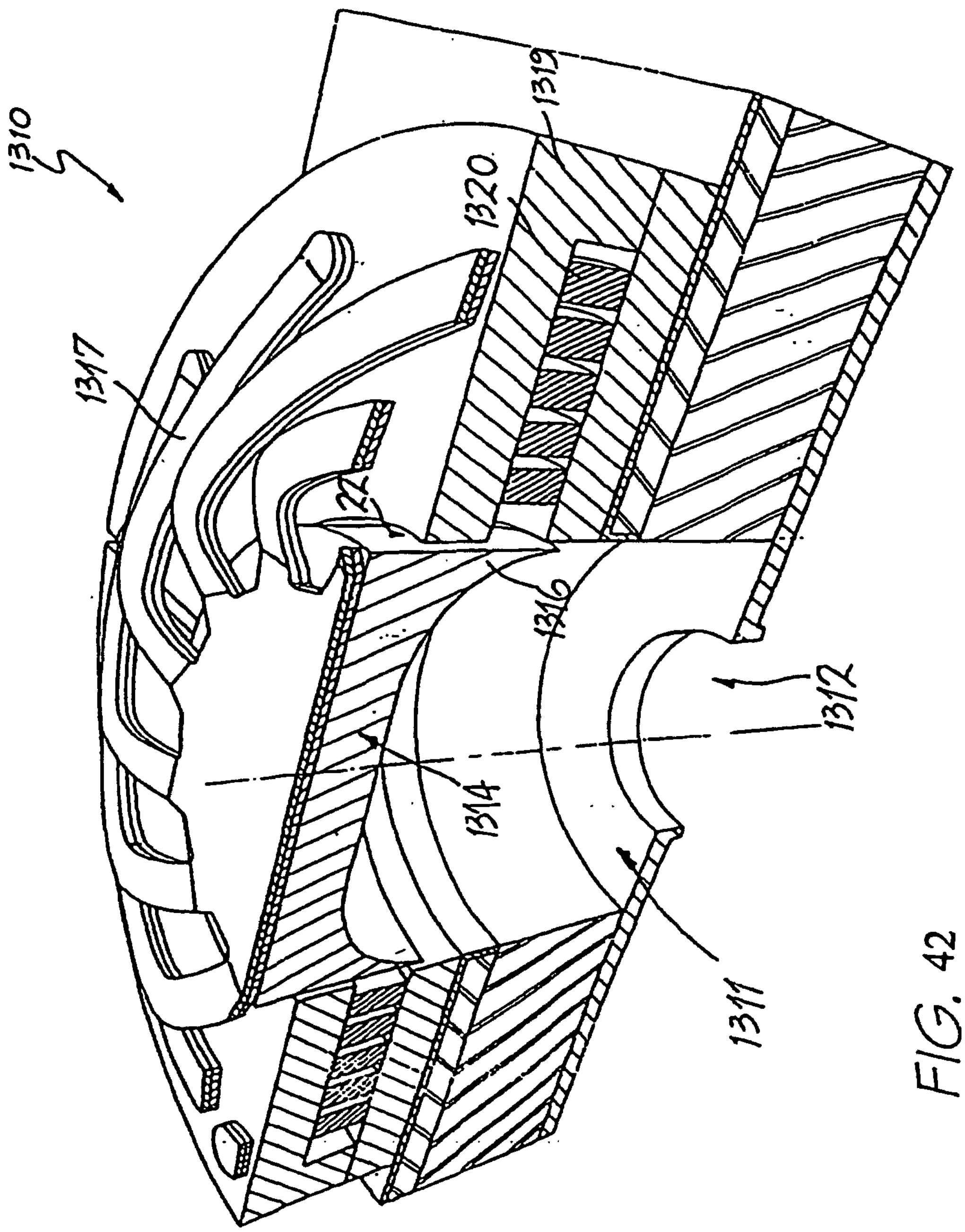

FIG. 42

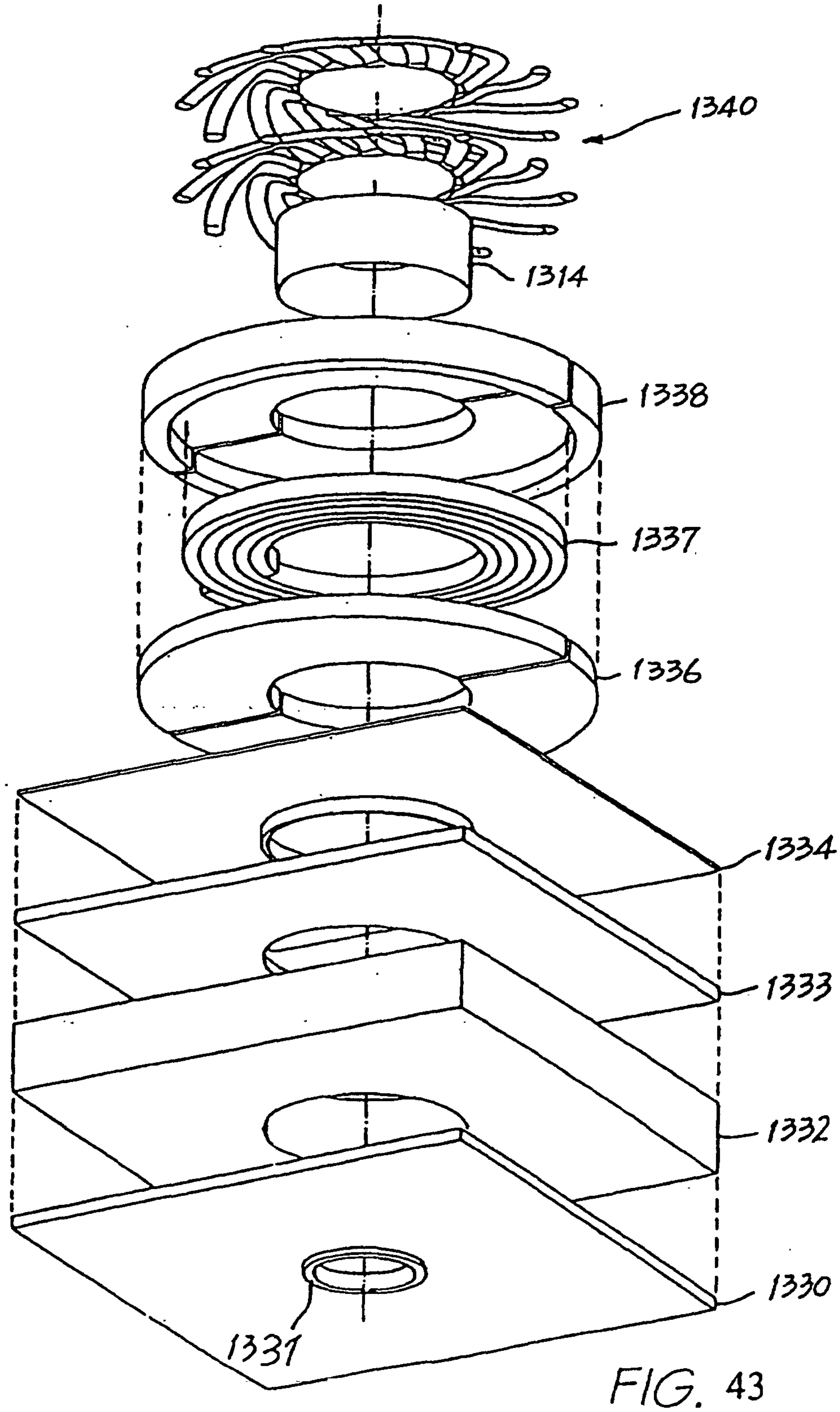

FIG. 43

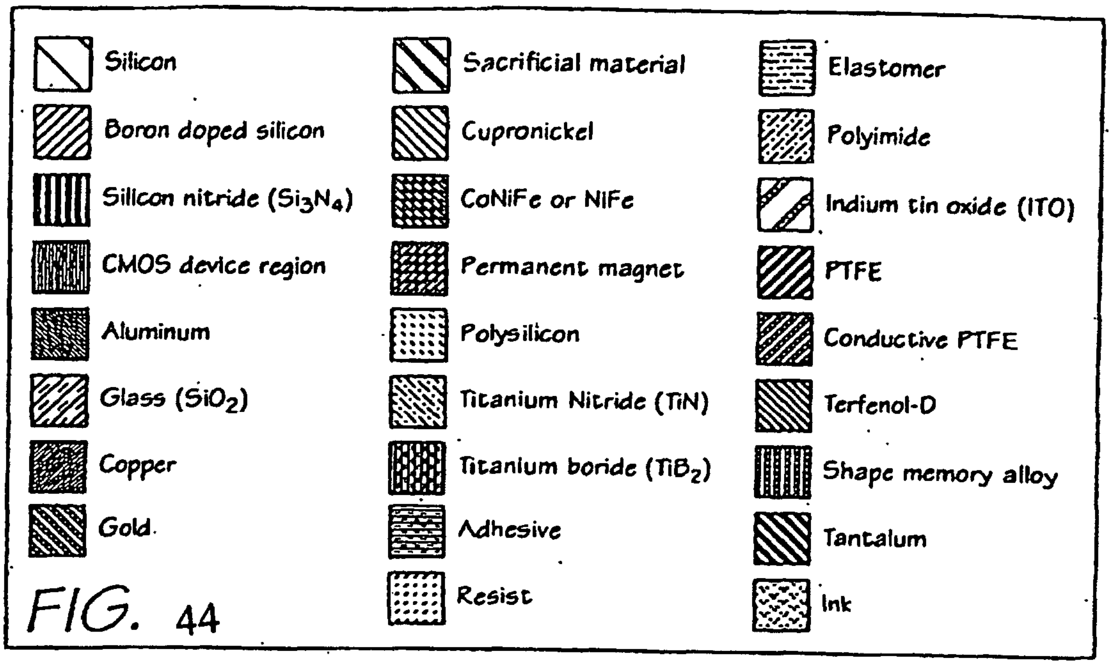

FIG. 44

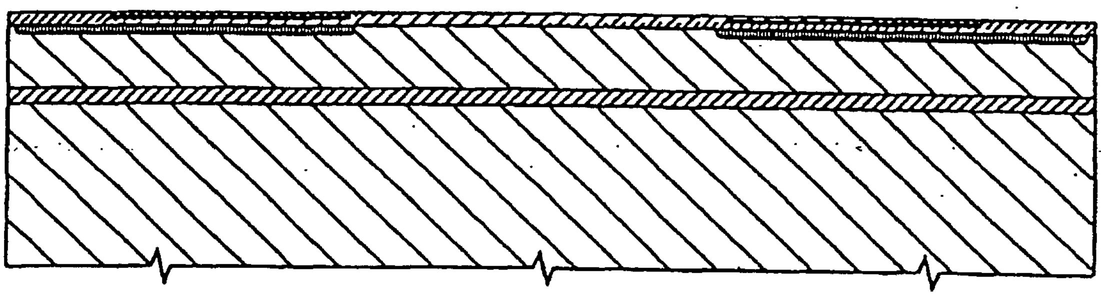

FIG. 45

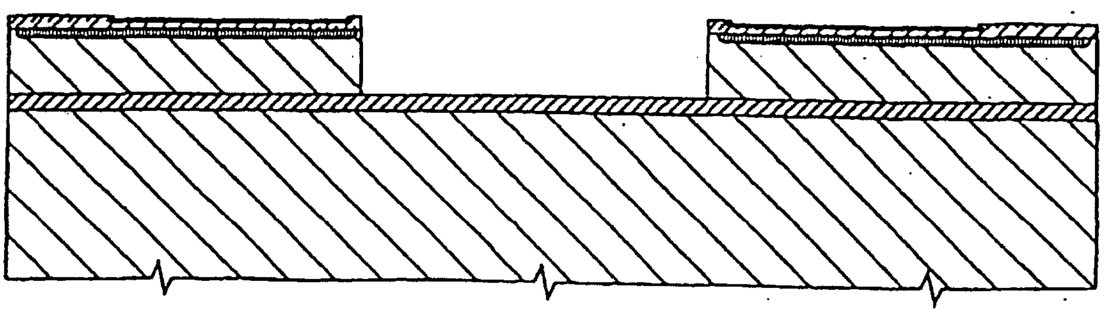

FIG. 46

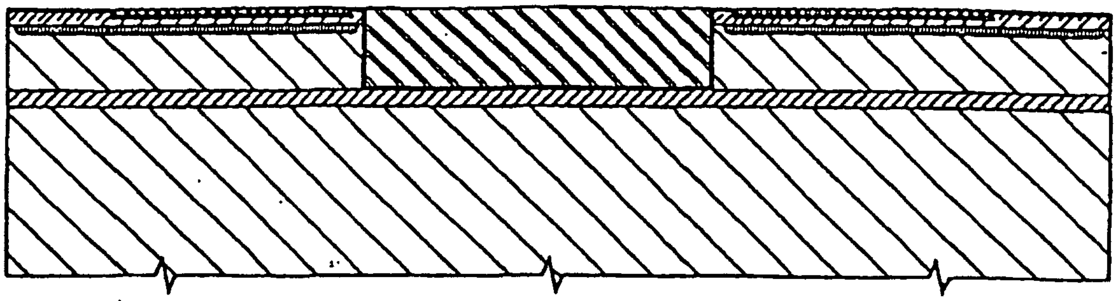

FIG. 47

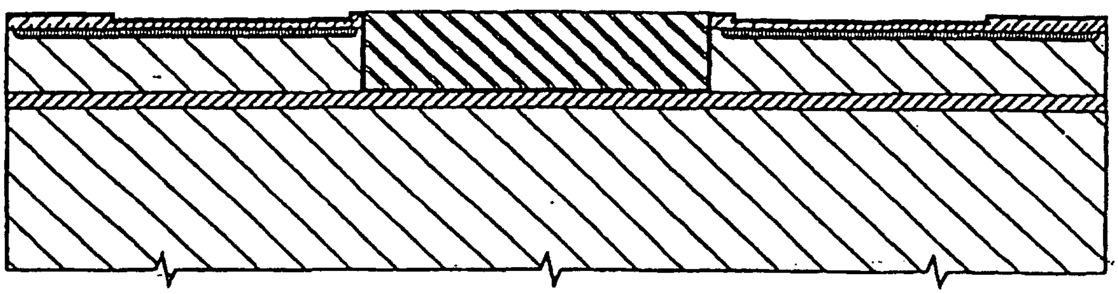

FIG. 48

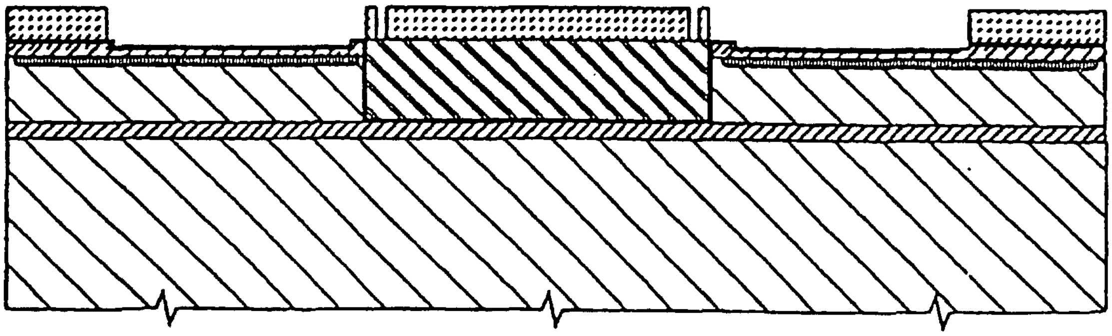

FIG. 49

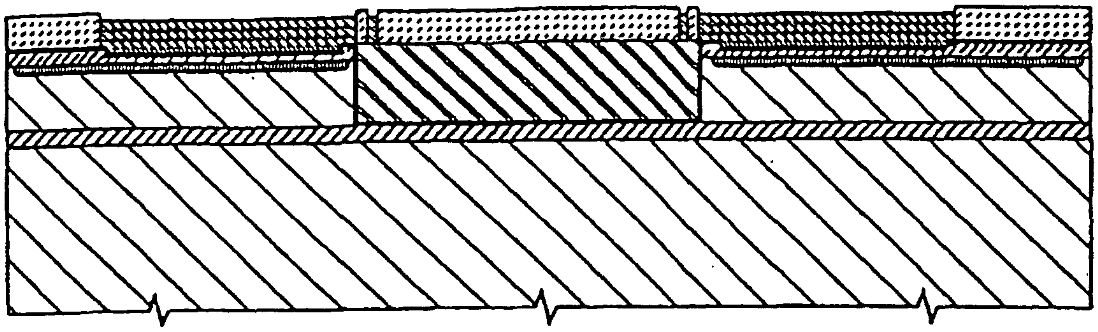

FIG. 50

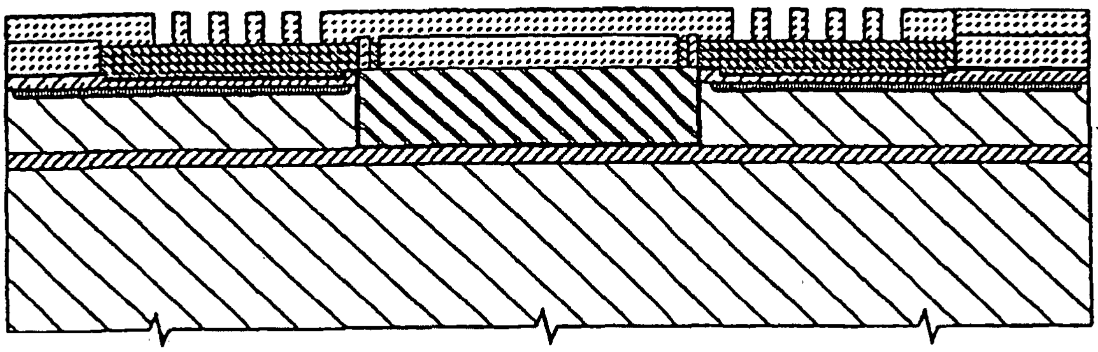

FIG. 51

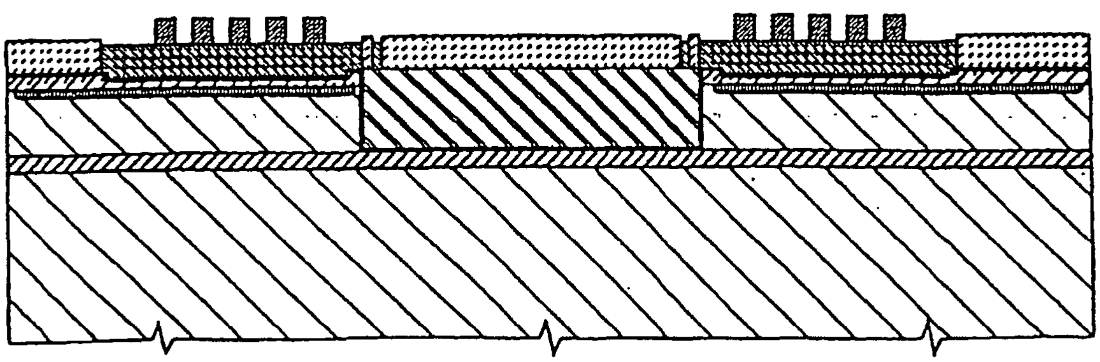

FIG. 52

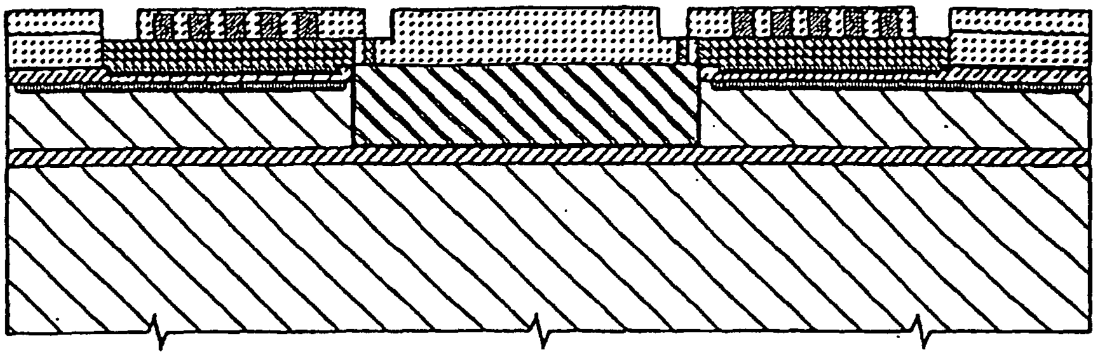

FIG. 53

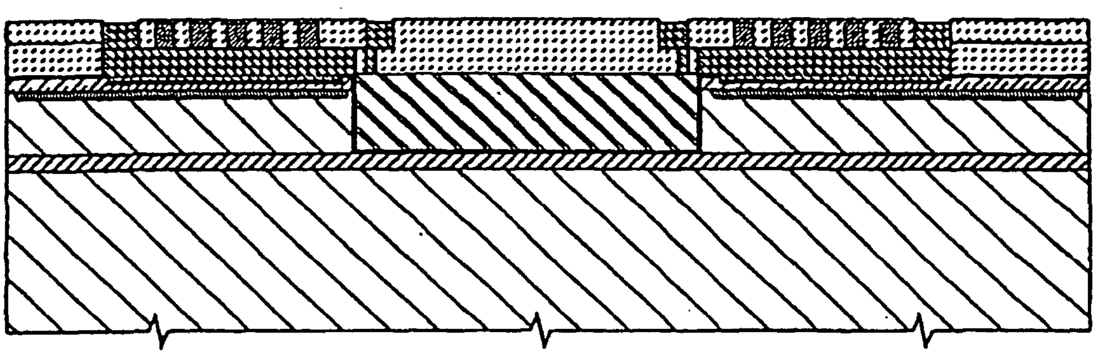

FIG. 54

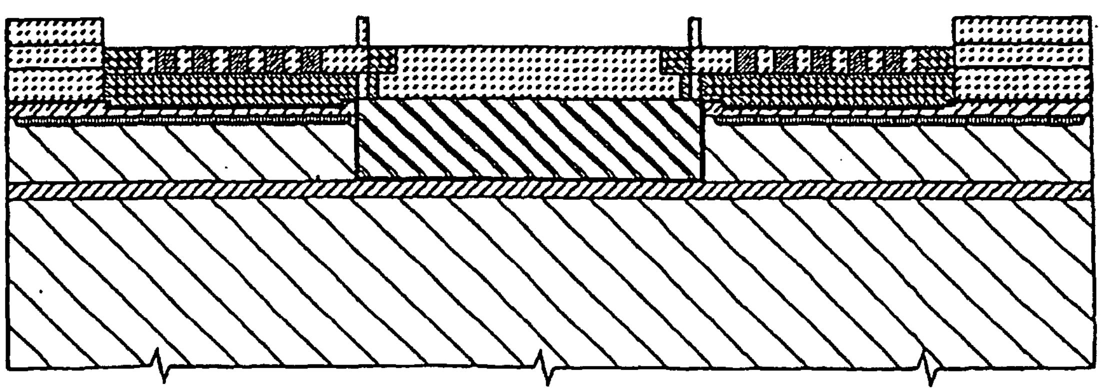

FIG. 55

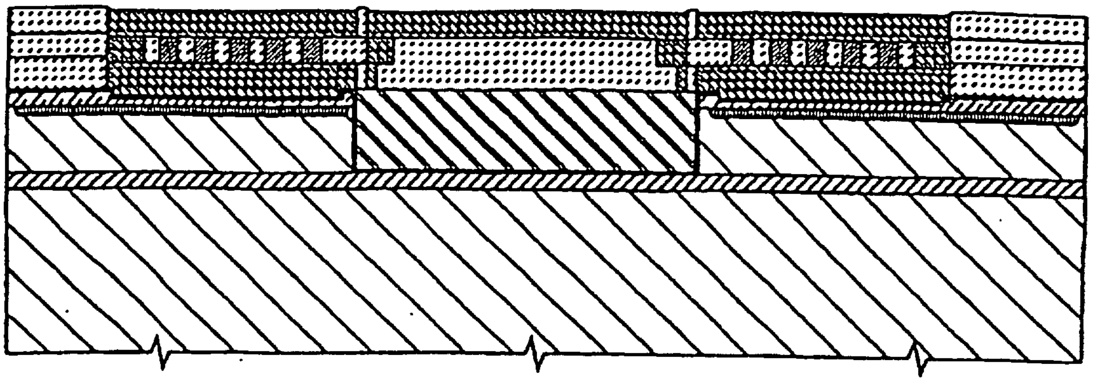

FIG. 56

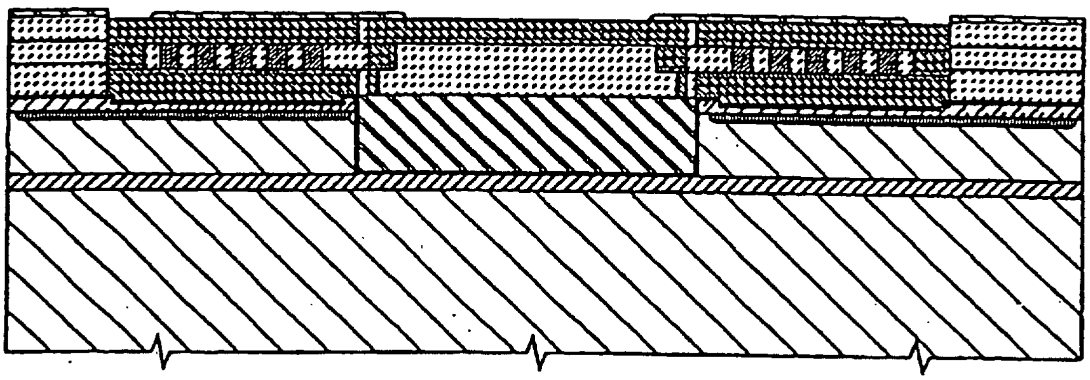

FIG. 57

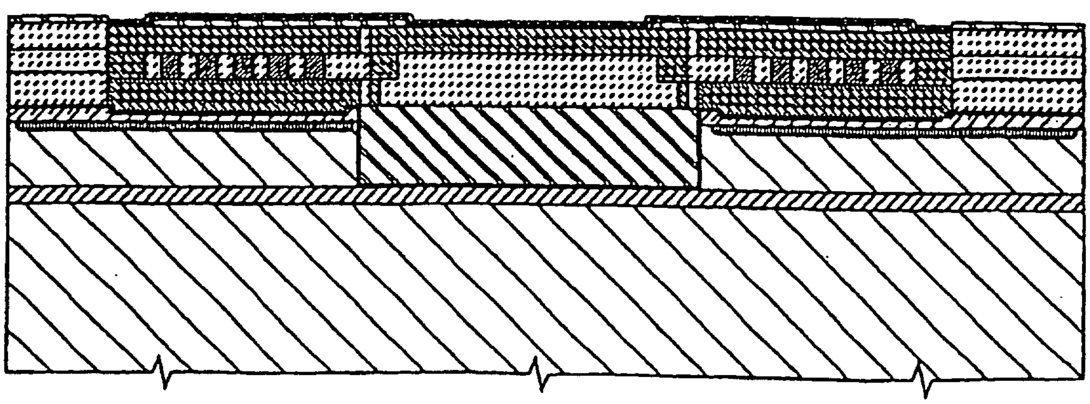

FIG. 58

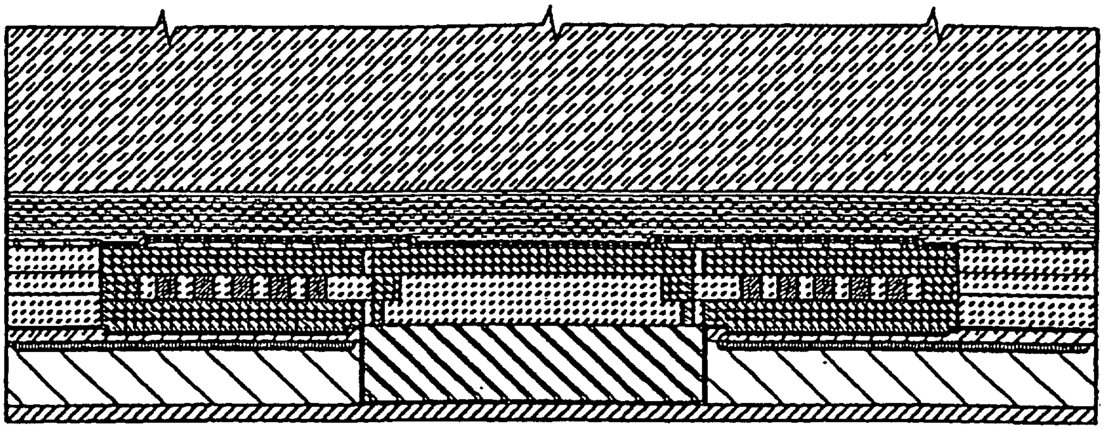
FIG. 59

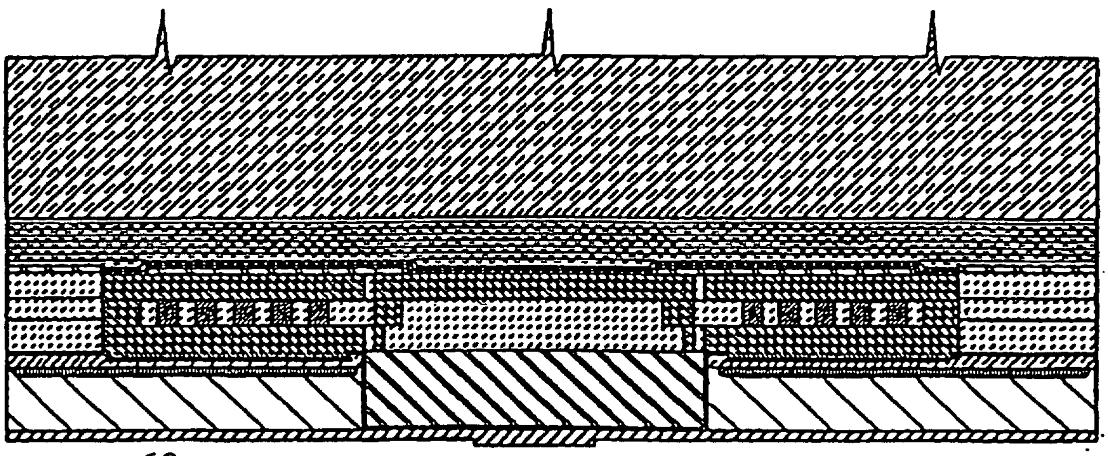
FIG. 60

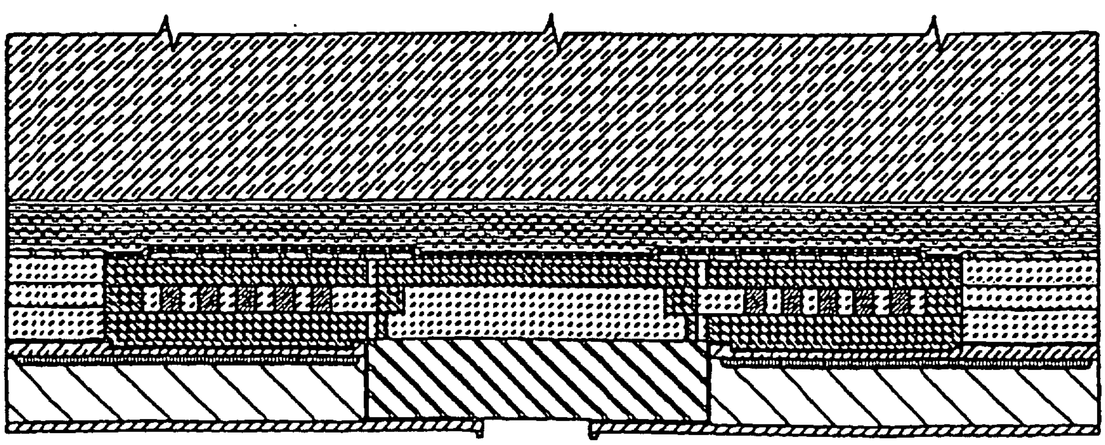
FIG. 61

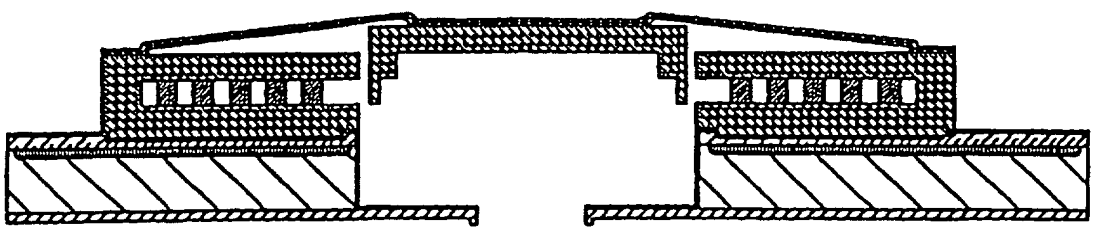

FIG. 62

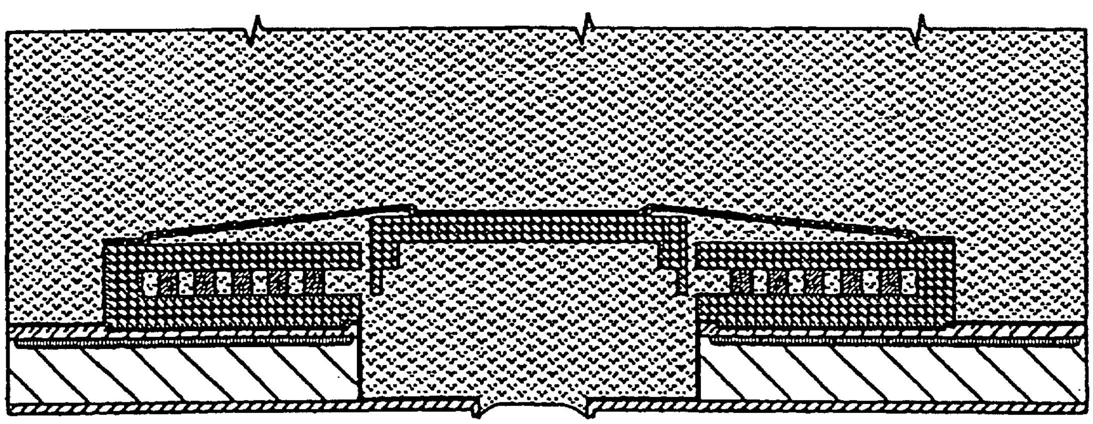

FIG. 63