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(54) **Inkjet nozzle with solenoid actuator**

Tintenstrahldüse mit elektromagnetischem Betätigungselement

Buse pour imprimante pour jet d'encre avec actionneur à solénoïde

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Description**Field of Invention**

5 **[0001]** The present invention relates to the field of ink jet printing systems.

Background of the Art

10 **[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 include 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.

15 **[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.

20 **[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).

25 **[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 inkjet printing.

30 **[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 utilized by several manufacturers including Elmjett and Scitex (see also US Patent No. 3373437 by Sweet et al)

35 **[0007]** Piezo-electric ink jet printers are also one form of commonly utilized 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.

40 **[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.

45 **[0009]** Electromagnetic ink-jet heads are known from JP-04368851 and JP-02034342.

50 **[0010]** 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.

55 **[0011]** Many ink jet printing mechanisms are known. Unfortunately, in mass production technologies, 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.

60 **[0012]** 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.

65 **[0013]** 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.

70 **[0014]** 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.

75 **[0015]** It would therefore be desirable if an efficient system for the mass production of ink jet print heads could be developed.

Summary of the invention

[0016] It is an object of the present invention to provide for an ink jet printing having a series of ink ejection nozzles, with the nozzles including an internal selective actuator mechanism activated on a nozzle by nozzle basis by the placement of a field around said nozzles.

[0017] Accordingly the invention provides an arrangement according to claim 1 with advantageous embodiments detailed in the dependent claims. The invention also provides a method in accordance with claim 13.

Brief Description of the Drawings

[0018] 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. 157 is a cross sectional view of a single ink jet nozzle as constructed in accordance with an embodiment in its quiescent state;

Fig. 158 is a cross sectional view of a single ink jet nozzle as constructed in accordance with an embodiment after reaching its stop position;

Fig. 159 is a cross sectional view of a single ink jet nozzle as constructed in accordance with an embodiment in the keeper face position;

Fig. 160 is a cross sectional view of a single ink jet nozzle as constructed in accordance with an embodiment after de-energizing from the keeper level.

Fig. 161 is an exploded perspective view illustrating the construction of an embodiment;

Fig. 162 is the cut out topside view of a single ink jet nozzle constructed in accordance with an embodiment in the keeper level;

Fig. 163 provides a legend of the materials indicated in Fig. 164 to Fig. 183; and

Fig. 164 to Fig. 183 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

[0019] The preferred embodiments and other embodiments will be discussed under separate headings with the heading including an U 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 IJ11 F

[0020] In an embodiment, there is provided an ink jet nozzle and chamber filled with ink. Within said jet nozzle chamber is located a static coil and a moveable coil. When energized, the static and movable coils are attracted towards one another, loading a spring. The ink drop ejected from the nozzle when the coils are de-energized. Turn now to Fig. 157 to Fig. 160, there is illustrated schematically the operation of an embodiment. In Fig. 157, there is shown a single inkjet nozzle chamber 1010 having an ink ejection port 1011 and ink meniscus in this position 1012. Inside the nozzle chamber 1010 are located a fixed or static coil 1014 and a moveable coil 1015. The arrangement of Fig. 157 illustrates the quiescent state in the ink jet nozzle chamber.

[0021] The two coils are then energised resulting in an attraction to one another. This results in the movable plate 1015 moving towards the static or fixed plate 1014 as illustrated in Fig. 158. As a result of the movement, springs 1018, 1019 are loaded. Additionally, the movement of coil 1015 may cause ink to flow out of the chamber 1010 in addition to a change in the shape of the meniscus 1012. The coils are energised for long enough for the moving coil 1015 to reach its position (approximate two microseconds). The coil currents are then turned to a lower "level" while the nozzle fills. The keeper power can be substantially less than the maximum current level utilised to move the plate 1015 because the magnetic gap between the plates 1014 and 1015 is at a minimum when the moving coil 1015 is at its stop position. The surface tension on the meniscus 1012 inserts a net force on the ink which results in nozzle refilling as illustrated in Fig. 159. The nozzle refilling replaces the volume of the piston withdrawal with ink in a process which should take approximately 100 microseconds.

[0022] Turning to Fig. 160, the coil current is then turned off and the moveable coil 1015 acts as a plunger which is accelerated to its normal position by the springs 1018, 1019 as illustrated in Fig. 160. The spring force on the plunger coil 1015 will be greatest at the beginning of its stroke and slows as the spring elastic stress falls to zero. As a result, the acceleration of plunger plate 1015 is high at the beginning of the stroke but decreases during the stroke resulting in a more uniform ink velocity during the stroke. The movement plate 1015 causes the meniscus to bulge and break off

performing ink drop 1020. The plunger coil 1015 in turn settles in its quiescent position until the next drop ejection cycle.

[0023] Turning now to Fig. 161, there is illustrated a perspective view of one form of construction of an ink jet nozzle 1010. The ink jet nozzle 1010 can be constructed on a silicon wafer base 1022 as part of a large array of nozzles 1010 which can be formed for the purposes of providing a print head having a certain dpi, for example, a 1600 dpi print head.

The print head 1010 can be constructed utilizing advanced silicon semi-conductor fabrication and micro machining and micro fabrication process technology. The wafer is first processed to include lower level drive circuitry (not shown) before being finished off with a two microns thick dioxide layer 1022 with appropriate vias for interconnection. Preferably, the CMOS layer can include one level of metal for providing basic interconnects. On top of the glass layer 1022 is constructed a nitride layer 1023 in which is embedded two coil layers 1025 and 1026. The coil layers 1025, 1026 can be embedded within the nitride layer 1023 through the utilisation of the well-known dual damascene process and chemical mechanical planarization techniques ("Chemical Mechanical Planarisation of Micro Electronic Materials" by Sterger Wald et al published 1997 by John Wiley and Sons Inc., New York, New York). The two coils 1025, 1026 arc interconnected utilizing a fire at their central point and arc further connected, by appropriate vias at ends 1028, 1029 to the end points 1028, 1029. Similarly, the moveable coil can be formed from two copper coils 1031, 1032 which are encased within a further nitride layer 1033. The copper coil 1031, 1032 and nitride layer 1033 also include torsional springs 1036-1039 which are formed so that the top moveable coil has a stable state away from the bottom fixed coil. Upon passing a current through the various copper coils, the top copper coils 1031, 1032 are attracted to the bottom copper coils 1025, 1026 thereby resulting in a loading being placed on the torsional springs 1036-1039 such that, when the current is turned off, the springs 1036-1039 act to move the top moveable coil to its original position. The nozzle chamber can be formed via nitride wall portions e.g. 1040, 1041 having slots between adjacent wall portions. The slots allow for the flow of ink into the chamber as required. A top nitride plate 1044 is provided to cap the top of the internals of 1010 and to provide in flow channel support. The nozzle plate 1044 includes a series of holes 1045 provided to assist in sacrificial etching of lower level layers. Also provided is the ink injection nozzle 1011 having a ridge around its side so as to assist in resisting any in flow on to the outside surface of the nozzle 1010. The etched through holes 1045 are of much smaller diameter than the nozzle hole 1011 and, as such, surface tension will act to retain the ink within the through holes of 1045 whilst simultaneously the injection of ink from nozzle 1011.

[0024] As mentioned previously, the various layers of the nozzle 1010 can be constructed in accordance with standard semi-conductor and micro mechanical techniques. These techniques utilize the dual damascene process as mentioned earlier in addition to the utilisation of sacrificial etch layers to provide support for structures which are later released by means of etching the sacrificial layer.

[0025] The ink can be supplied within the nozzle 1010 by standard techniques such as providing ink channels along the side of the wafer so as to allow the flow of ink into the area under the surface of nozzle plate 1044. Alternatively, ink channel portals can be provided through the wafer via means of utilisation of a high density low pressure plasma etch processing system such as that available from surface technology system and known as their Advanced Silicon Edge (ASE) process. The etched portals 1045 being so small that surface tension affects not allow the ink to leak out of the small portal holes. In Fig. 162; there is shown a final assembled ink jet nozzle ready for the ejection of ink.

[0026] 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, 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. 164. For clarity, these diagrams may not be to scale, and may not represent a cross section though any single plane of the nozzle. Fig. 163 is a key to representation of various materials in these manufacturing diagrams, and those of other cross referenced ink jet configurations.
2. Deposit 0.5 microns of low stress PECVD silicon nitride (Si_3N_4). The nitride acts as a dielectric, and etch stop, a copper diffusion barrier, and an ion diffusion barrier. As the speed of operation of the print head is low, the high dielectric constant of silicon nitride is not important, so the nitride layer can be thick compared to sub-micron CMOS back-end processes.
3. Etch the nitride layer using Mask 1. This mask defines the contact via from the solenoid coil to the second-level metal contacts. This step is shown in Fig. 165.
4. Deposit 1 micron of PECVD glass.
5. Etch the glass down to nitride or second level metal using Mask 2. This mask defines first layer of the fixed solenoid. This step is shown in Fig. 166.
6. Deposit a thin barrier layer of Ta or TaN.
7. 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.
8. Electroplate 1 micron of copper.
9. Planarize using CMP. Steps 2 to 9 represent a copper dual damascene process. This step is shown in Fig. 167.
10. Deposit 0.5 microns of low stress PECVD silicon nitride.

11. Etch the nitride layer using Mask 3. This mask defines the defines the vias from the second layer to the first layer of the fixed solenoid. This step is shown in Fig. 168.
12. Deposit 1 micron of PECVD glass.
13. Etch the glass down to nitride or copper using Mask 4. This mask defines second layer of the fixed solenoid. This step is shown in Fig. 169.
14. Deposit a thin barrier layer and seed layer.
15. Electroplate 1 micron of copper.
16. Planarize using CMP. Steps 10 to 16 represent a second copper dual damascene process. This step is shown in Fig. 170.
17. Deposit 0.5 microns of low stress PECVD silicon nitride.
18. Deposit 0.1 microns of PTFE. This is to hydrophobize the space between the two solenoids, so that when the nozzle fills with ink, this space forms an air bubble. The allows the upper solenoid to move more freely.
19. Deposit 4 microns of sacrificial material. This forms the space between the two solenoids.
20. Deposit 0.1 microns of low stress PECVD silicon nitride.
21. Etch the nitride layer, the sacrificial layer, the PTFE layer, and the nitride layer of step 17 using Mask 5. This mask defines the vias from the first layer of the moving solenoid to the second layer the fixed solenoid. This step is shown in Fig. 171.
22. Deposit 1 micron of PECVD glass.
23. Etch the glass down to nitride or copper using Mask 6. This mask defines first layer of the moving solenoid. This step is shown in Fig. 172.
24. Deposit a thin barrier layer and seed layer.
25. Electroplate 1 micron of copper.
26. Planarize using CMP. Steps 20 to 26 represent a third copper dual damascene process. This step is shown in Fig. 173.
27. Deposit 0.1 microns of low stress PECVD silicon nitride.
28. Etch the nitride layer using Mask 7. This mask defines the vias from the second layer the moving solenoid to the first layer of the moving solenoid. This step is shown in Fig. 174.
29. Deposit 1 micron of PECVD glass.
30. Etch the glass down to nitride or copper using Mask 8. This mask defines second layer of the moving solenoid. This step is shown in Fig. 175.
31. Deposit a thin barrier layer and seed layer
32. Electroplate 1 micron of copper.
33. Planarize using CMP. Steps 27 to 33 represent a fourth copper dual damascene process. This step is shown in Fig. 176.
34. Deposit 0.1 microns of low stress PECVD silicon nitride.
35. Etch the nitride using Mask 9. This mask defines the moving solenoid, including its springs, and allows the sacrificial material in the space between the solenoids to be etched. It also defines the bond pads. This step is shown in Fig. 177.
36. Wafer probe. AU electrical connections are complete at this point, bond pads are accessible, and the chips are not yet separated.
37. Deposit 10 microns of sacrificial material.
38. Etch the sacrificial material using Mask 10. This mask defines the nozzle chamber wall. This step is shown in Fig. 178.
39. Deposit 3 microns of PECVD glass.
40. Etch to a depth of 1 micron using Mast 11. This mask defines the nozzle rim. This step is shown in Fig. 179.
41. Etch down to the sacrificial layer using Mask 12. This mask defines the roof of the nozzle chamber, and the nozzle itself. This step is shown in Fig. 180.
42. Back-etch completely through the silicon wafer (with, for example, an ASE Advanced Silicon Etcher from Surface Technology Systems) using Mask 7. This mask defines the ink inlets which are etched though the wafer. The wafer is also diced by this etch. This step is shown in Fig. 181.
43. Etch the sacrificial material. The nozzle chambers are cleared, the actuators freed, and the chips are separated by this etch. This step is shown in Fig. 182.
44. Mount the print heads in their packaging, which may be a molded plastic former incorporating ink channels which supply the appropriate color ink to the ink inlets at the back of the wafer.
45. Connect the print heads to their interconnect systems. For a low profile connection with minimum disruption of airflow, TAB may be used. Wire bonding may also be used if the printer is to be operated with sufficient clearance to the paper.
46. Hydrophobize the front surface of the print heads.

47. Fill the completed print heads with ink and test them. A filled nozzle is shown in Fig. 183.

IJ USES

[0027] 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

[0028] The embodiments of the invention use an ink jet printer type device. Of course many different devices could be used. However presently popular Inkjet printing technologies are unlikely to be suitable.

[0029] 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.

[0030] 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 heads with 19,200 nozzles.

[0031] Ideally, the inkjet 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).

[0032] 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.

[0033] The inkjet designs shown here are 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

[0034] For case 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.

[0035] 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

[0036] 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 when referring to a particular case:

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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 Electromagnetic 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
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
U36US	IJ36	Dual Chamber Single Vertical Actuator Ink Jet
IJ37US	IJ37	Dual Nozzle Single Horizontal Fulcrum Actuator Ink Jet
IJ38US	IJ38	Dual Nozzle Single Horizontal Actuator Ink Jet

(continued)

Docket No.	Reference	Title
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
UJ42US	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

[0037] Eleven important characteristics of the fundamental operation of individual inkjet nozzles have been identified. These characteristics 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.

[0038] 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)

[0039] 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 configuration 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.

[0040] 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.

[0041] 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.

[0042] 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.

[0043] 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	◆ 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 ($\sim 10 \mu\text{s}$) ◆ High voltage drive transistors required ◆ Full pagewidth print heads Impractical due to actuator size	◆ Seiko Epson, Usul et al JP 253401/96 ◆ IJ04

(continued)

Actuator Mechanism	Description	Advantages	Disadvantages	Examples
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

(continued)

Actuator Mechanism	Description	Advantages	Disadvantages	Examples
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 Curie temperature (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

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(continued)

Actuator Mechanism	Description	Advantages	Disadvantages	Examples
Magnetostriction	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 - Past 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 current required - Copper metalization should be used for long electromigration lifetime and low - 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

(continued)

Actuator Mechanism	Description	Advantages	Disadvantages	Examples
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, U32 ◆ 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 μ m long PTFE bend actuator with polysilicon heater and 15 m W power input can provide 180 μ N force and 10 μ m 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 ◆ U21, IJ22, IJ23, IJ24 ◆ IJ27, IJ28, IJ29, IJ30 ◆ IJ31, IJ42, IJ43, IJ44

(continued)

Actuator Mechanism	Description	Advantages	Disadvantages	Examples
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 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 austenitic state. The shape of the actuator in its martensitic state is deformed relative to the austenitic 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

(continued)

Actuator Mechanism	Description	Advantages	Disadvantages	Examples
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 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, U04 - 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

(continued)

Operational mode	Description	Advantages	Disadvantages	Examples
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

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(continued)

Operational mode	Description	Advantages	Disadvantages	Examples
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

Auxillary mechanism (applied to all nozzles)

Auxillary 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

(continued)

Auxiliary Mechanism	Description	Advantages	Disadvantages	Examples
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 fiber 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

(continued)

Auxiliary Mechanism	Description	Advantages	Disadvantages	Examples
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

Actuator amplification or modification method

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

(continued)

Actuator amplification	Description	Advantages	Disadvantages	Examples
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

(continued)

Actuator amplification	Description	Advantages	Disadvantages	Examples
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
Colled actuator	A bend actuator is colled 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 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

(continued)

Actuator amplification	Description	Advantages	Disadvantages	Examples
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

(continued)

Actuator amplification	Description	Advantages	Disadvantages	Examples
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, BUP 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 kagation 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

(continued)

Actuator motion	Description	Advantages	Disadvantages	Examples
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 austenitic 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 of 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

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(continued)

Actuator motion	Description	Advantages	Disadvantages	Examples
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

(continued)

Nozzle refill method	Description	Advantages	Disadvantages	Examples
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, EP0771 658 A2 and related patent applications ♦ Possible operation of the following: ♦ IJ01-IJ07, IJ09- IJ12 ♦ IJ14, IJ16, IJ20, IJ22, ♦ IJ23-IJ34, 1136-IJ41 ♦ IJ44

(continued)

Inlet back-flow restriction method	Description	Advantages	Disadvantages	Examples
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	♦ ResWcu.mnll 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

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(continued)

Inlet back-flow restriction method	Description	Advantages	Disadvantages	Examples
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

(continued)

Nozzle Clearing method	Description	Advantages	Disadvantages	Examples
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	♦ Sliverbrook, 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, IJ43
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

(continued)

Nozzle Clearing method	Description	Advantages	Disadvantages	Examples
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 system
Separate ink boiling heater	A separate heater is provided at the nozzle although the normal drop e-action 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 U 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 Sercelet al., SPIE, Vol. 998 Excimer Beam Applications. pp. 76-83 ♦ 1993 Watanabe ct 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

(continued)

Nozzle plate construction	Description	Advantages	Disadvantages	Examples
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

(continued)

Nozzle plate construction	Description	Advantages	Disadvantages	Examples
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

Drop ejection direction

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 handling	◆ 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-ptt 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 - Maximum ◆ 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	◆ Silvebrook, EP0771 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

(continued)

Ejection direction	Description	Advantages	Disadvantages	Examples
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 0771658 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 0771658 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

(continued)

Ink type	Description	Advantages	Disadvantages	Examples
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 U 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 dyes 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

[0044] 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.

Ink Jet Manufacturing

[0045] Further, the present application may utilize advanced semiconductor fabrication techniques in the construction of large arrays of ink jet printers.

Fluid Supply

[0046] Further, the present application may utilize an ink delivery system to the ink jet head. De

MEMS Technology

[0047] Further, the present application may utilize advanced semiconductor microelectromechanical techniques in the construction of large arrays of ink jet printers.

IR Technologies

[0048] Further, the present application may include the utilization of a disposable camera system

DotCard Technologies

[0049] Further, the present application may include the utilization of a data distribution system.

Artcam Technologies

[0050] Further, the present application may include the utilization of camera and data processing techniques such as an Artcam type device

[0051] 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 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 nozzle arrangement comprising:

- (a) a nozzle chamber (1010) having an ink injection port (1011) at one wall of said chamber;
- (b) a fixed electric coil (1014) located within the chamber or within a wall of said chamber; said arrangement being **characterised by** further comprising
- (c) a moveable plate (1015), in which embedded is an electric coil, located close to said fixed electric coil (1014) such that when the amount of current passing through said coils is altered, the movable plate (1015) undergoes corresponding movement towards or away from said fixed electric coil (1014) and wherein said movement is utilized to eject ink from said nozzle chamber (1010) via said ink injection port (1011).

2. An ink jet nozzle arrangement as claimed in claim 1 further comprising:

spring means (1018) connected to said moveable plate (1015) wherein said moveable plate goes from a quiescent position to a spring loaded position upon activation of said coils and upon deactivation of said coils said spring means causes said moveable coil to return to its quiescent position and to thereby eject ink from said ink ejection port (1011).

3. An ink jet nozzle arrangement as claimed in claims 1 or 2 wherein said fixed electric coil (1014) comprises a stacked multi level spiral (1025,1026) of conductive material.

4. An ink jet nozzle arrangement claimed in claim 3 wherein said stacked conductive material is interconnected at a central axial point of said spiral.

5. An ink jet nozzle arrangement as claimed in any of claims 1 to 4 wherein said coils are electrically connected together to form a combined circuit.

6. An ink jet nozzle arrangement claimed in claim 2 wherein said spring means (1018) comprises torsional springs attached to said moveable coil.

7. An ink jet nozzle arrangement claimed in claim 6 wherein a conductive strip contact to said coils is located within said torsional springs.

8. An ink jet nozzle arrangement claimed in any previous claim wherein said coils comprise substantially copper.

9. An ink jet nozzle arrangement as claimed in any of claims 1 to 8 wherein said coils are formed from utilization of a damascene construction process.
10. An ink jet nozzle arrangement as claimed in any of claims 1 to 9 wherein said nozzle is constructed utilizing a sacrificial etch to release the structure of said moveable coil.
11. An ink jet nozzle arrangement as claimed in any of claims 1 to 10 wherein said nozzle chamber includes a series of slots within the walls of said nozzle chamber so as to allow the supply of ink to said nozzle chamber.
12. An ink jet nozzle arrangement as claimed in claim 10 wherein an outer surface of said nozzle chamber (1010) includes a series of small etched holes (1045) for the etching of any sacrificial layer utilized in the construction of said ink jet print nozzle.
13. A method of ejecting ink from a nozzle chamber (1010) utilizing the electro-magnetic forces between two coils embedded into plates (1014, 1015) to cause movement of at least one of said plates (1015), the movement further causing the consequential ejection of ink from said nozzle chamber.

Patentansprüche

1. Tintenstrahl-Düsenanordnung, umfassend:

(a) eine Düsenkammer (1010) mit einer Tintenausstoßöffnung (1011) an einer Wand der Kammer;
 (b) eine feststehende elektrische Spule (1014), die innerhalb der Kammer oder innerhalb einer Wand der Kammer sitzt; wobei die Anordnung **dadurch gekennzeichnet ist, dass** sie darüber hinaus umfasst:
 (c) eine bewegbare Platte (1015), in der eine elektrische Spule eingebettet ist, die nahe an der feststehenden elektrischen Spule (1014) sitzt, so dass, wenn sich die Menge des die Spulen durchlaufenden Stroms ändert, die bewegbare Platte (1015) eine entsprechende Bewegung zur feststehenden elektrischen Spule (1014) oder von dieser weg durchmacht, und wobei die Bewegung dazu genutzt wird, Tinte aus der Düsenkammer (1010) über die Tintenausstoßöffnung (1011) auszustoßen.

2. Tintenstrahl-Düsenanordnung nach Anspruch 1, darüber hinaus umfassend:

eine Federeinrichtung (1018), die mit der bewegbaren Platte (1015) verbunden ist, wobei auf eine Aktivierung der Spulen hin die bewegbare Platte sich von einer Ruheposition in eine federvorgespannte Position bewegt, und auf eine Deaktivierung der Spulen hin die Federeinrichtung bewirkt, dass die bewegbare Spule in ihre Ruheposition zurückkehrt, und **dadurch** Tinte aus der Tintenausstoßöffnung (1011) ausgestoßen wird.

3. Tintenstrahl-Düsenanordnung nach Anspruch 1 oder 2, wobei die feststehende elektrische Spule (1014) in mehreren Ebenen übereinander liegende Spiralen (1025, 1026) aus leitendem Material umfasst.

4. Tintenstrahl-Düsenanordnung nach Anspruch 3, wobei das übereinander liegende, leitende Material an einem zentralen, axialen Punkt der Spirale verbunden ist.

5. Tintenstrahl-Düsenanordnung nach einem der Ansprüche 1 bis 4, wobei die Spulen elektrisch aneinander angeschlossen sind, um einen kombinierten Schaltkreis zu bilden.

6. Tintenstrahl-Düsenanordnung nach Anspruch 2, wobei die Federeinrichtung (1018) Torsionsfedern umfasst, die an der bewegbaren Spule befestigt sind.

7. Tintenstrahl-Düsenanordnung nach Anspruch 6, wobei innerhalb der Torsionsfedern ein leitender Streifenkontakt zu den Spulen sitzt.

8. Tintenstrahl-Düsenanordnung nach einem der vorhergehenden Ansprüche, wobei die Spulen im Wesentlichen Kupfer enthalten.

9. Tintenstrahl-Düsenanordnung nach einem der Ansprüche 1 bis 8, wobei die Spulen unter Nutzung eines Damaszener-Ausführungsprozesses gebildet sind.

10. Tintenstrahl-Düsenanordnung nach einem der Ansprüche 1 bis 9, wobei die Düse unter Nutzung einer Opferätzung ausgeführt wird, um die Struktur der bewegbaren Spule freizulegen.
11. Tintenstrahl-Düsenanordnung nach einem der Ansprüche 1 bis 10, wobei die Düsenkammer in ihrer Wand eine Reihe von Schlitzten umfasst, um die Zufuhr von Tinte zur Düsenkammer zu ermöglichen.
12. Tintenstrahl-Düsenanordnung nach Anspruch 10, wobei eine Außenfläche der Düsenkammer (1010) für das Ätzen einer Opferschicht, die bei der Ausführung der Tintenstrahl-Druckdüse verwendet wird, eine Reihe von kleinen geätzten Löchern (1045) umfasst.
13. Verfahren zum Ausstoßen von Tinte aus einer Düsenkammer (1010) unter Ausnutzung der elektromagnetischen Kräfte zwischen zwei in Platten (1014, 1015) eingebetteten Spulen, um eine Bewegung zumindest einer der Platten (1015) zu verursachen, wobei die Bewegung weiterführend das daraus folgende Ausstoßen von Tinte aus der Düsenkammer bewirkt.

Revendications

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

(a) une chambre de buse (1010) ayant un port d'injection d'encre (1011) à une paroi de ladite chambre ;
 (b) une bobine électrique fixe (1014) située à l'intérieur de la chambre ou à l'intérieur d'une paroi de ladite chambre ; ledit agencement étant **caractérisé en ce qu'il** comporte en outre
 (c) une plaque mobile (1015), dans laquelle est incorporée une bobine électrique, située proche de ladite bobine électrique fixe (1014) de sorte que lorsque la quantité de courant passant à travers lesdites bobines est changée, la plaque mobile (1015) se déplace de manière correspondante vers ladite bobine électrique fixe (1014) ou à l'écart de celle-ci, et dans lequel ledit déplacement est utilisé pour éjecter de l'encre depuis la chambre de buse (1010) par ledit port d'injection (1011).

2. Agencement de buse de jet d'encre comme revendiqué dans la revendication 1 comprenant en outre :

des moyens de ressort (1018) connectés à ladite plaque mobile (1015) dans lesquels ladite plaque mobile va d'une position de repos vers une position de ressort chargé sur activation desdites bobines et sur désactivation desdites bobines lesdits moyens de ressort provoquent un retour de la bobine mobile à sa position de repos et ainsi une éjection de l'encre dudit corps d'éjection d'encre (1011).

3. Agencement de buse de jet d'encre comme revendiqué dans la revendication 1 ou 2 dans lequel ladite bobine électrique fixe (1014) comporte une spirale à niveaux multiples empilés (1025, 1026) de matériaux conducteurs.

4. Agencement de buse de jet d'encre comme revendiqué dans la revendication 3 dans lequel lesdits matériaux conducteurs empilés sont interconnectés à un point axial central de ladite spirale.

5. Agencement de buse de jet d'encre comme revendiqué dans l'une quelconque des revendications 1 à 4 dans lequel lesdites bobines sont connectées électriquement ensemble pour former un circuit combiné.

6. Agencement de buse de jet d'encre revendiqué dans la revendication 2 dans lequel lesdits moyens de ressort (1018) comportent des ressorts de torsion attachés à ladite bobine mobile.

7. Agencement de buse de jet d'encre revendiqué dans la revendication 6 dans lequel un contact à bande conductrice auxdites bobines est situé à l'intérieur desdits ressorts de torsion.

8. Agencement de buse de jet d'encre revendiqué dans l'une quelconque des revendications précédentes dans lequel lesdites bobines comportent substantiellement du cuivre.

9. Agencement de buse de jet d'encre comme revendiqué dans l'une quelconque des revendications 1 à 8 dans lequel lesdites bobines sont formées par utilisation d'un procédé de construction de damasquinage.

10. Agencement de buse de jet d'encre comme revendiqué dans l'une des revendications 1 à 9 dans lequel ladite buse

est construite en utilisation une attaque sacrificielle pour libérer la structure de ladite bobine mobile.

5 **11.** Agencement de buse de jet d'encre comme revendiqué dans l'une quelconque des revendications 1 à 10 dans lequel lesdites chambres de buses incluent une série de fentes à l'intérieur des parois de ladite chambre de buse de manière à autoriser la fourniture d'encre à ladite chambre de buse.

10 **12.** Agencement de buse de jet d'encre comme revendiqué dans la revendication 10 dans lequel une surface externe de ladite chambre de buse (1010) inclut une série de petits trous d'attaque (1045) pour l'attaque d'une quelconque des couches sacrificielles utilisées dans la construction de ladite buse d'impression de jet d'encre.

15 **13.** Procédé d'éjection d'encre depuis une chambre de buse (1010) utilisant les forces électromagnétiques entre deux bobines encastrées dans des plaques (1014, 1015) pour déplacer au moins l'une desdites plaques (1015), le déplacement provoquant en conséquence l'éjection d'encre depuis ladite chambre de buse.

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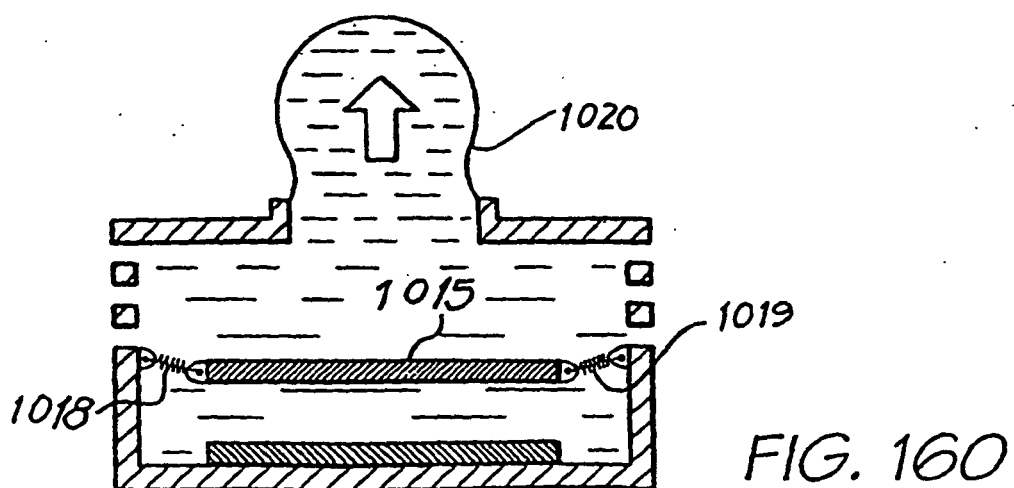
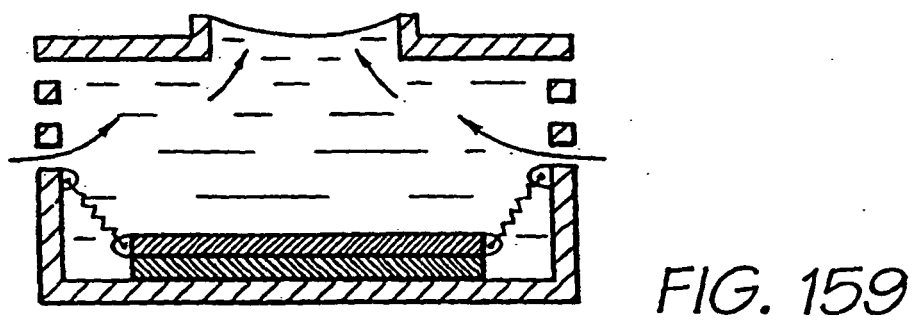
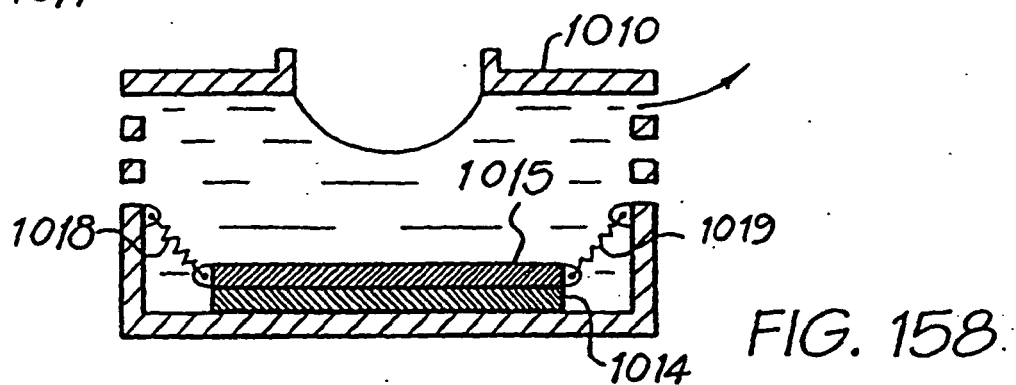
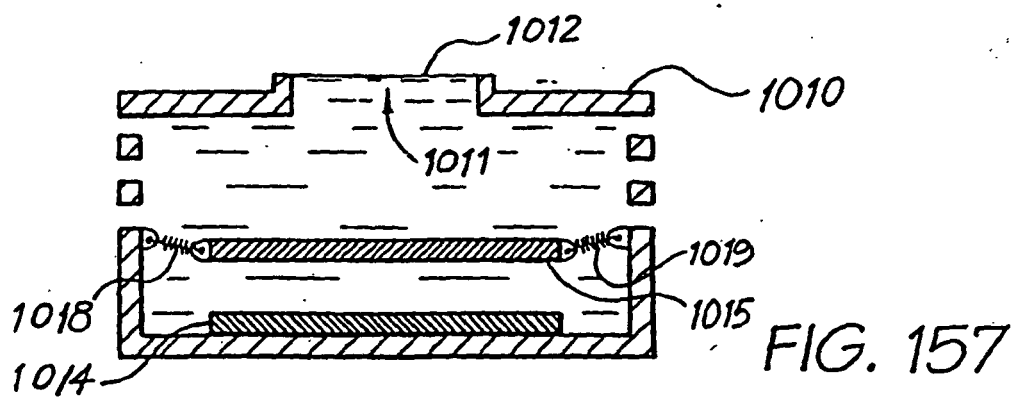
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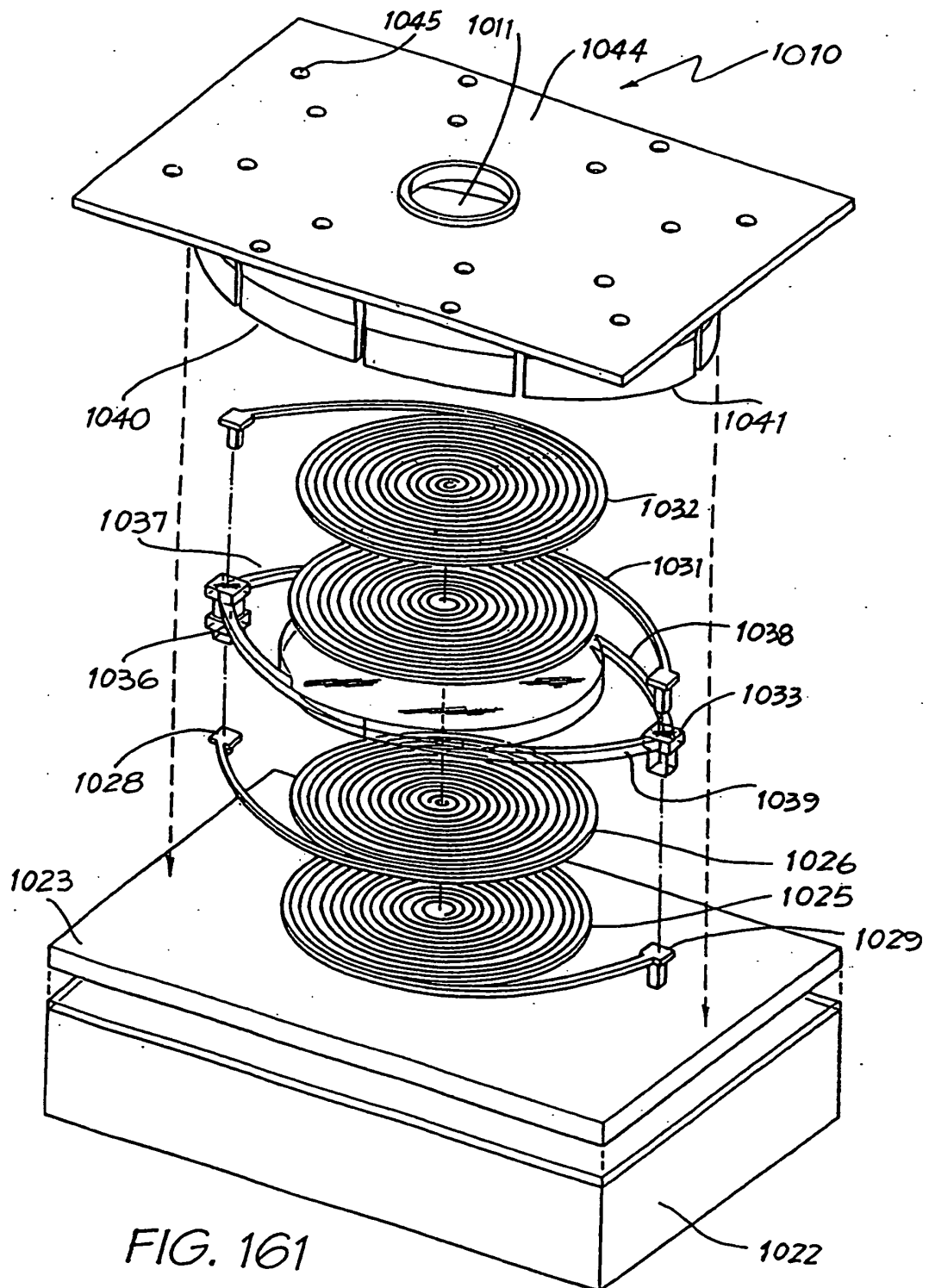
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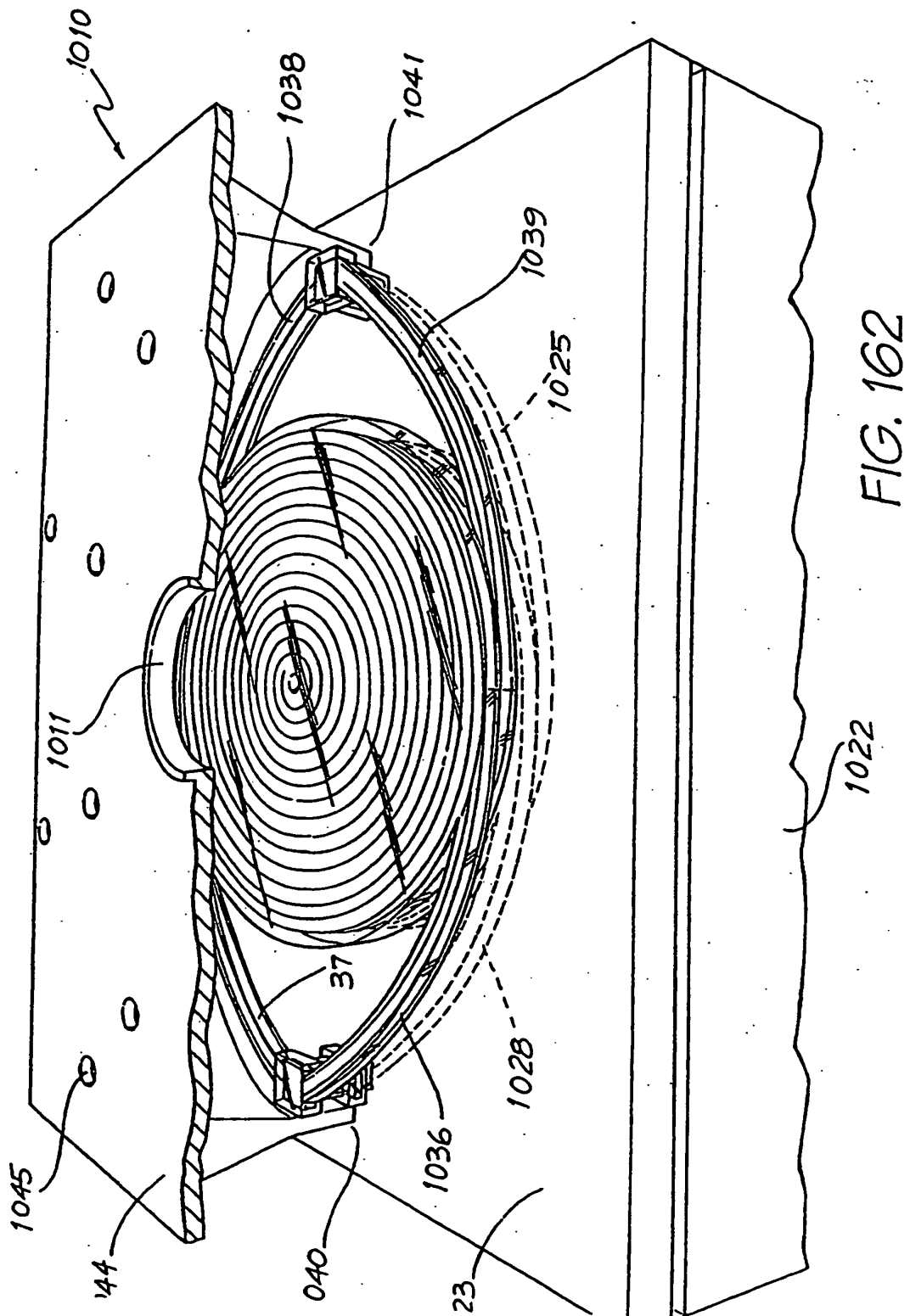
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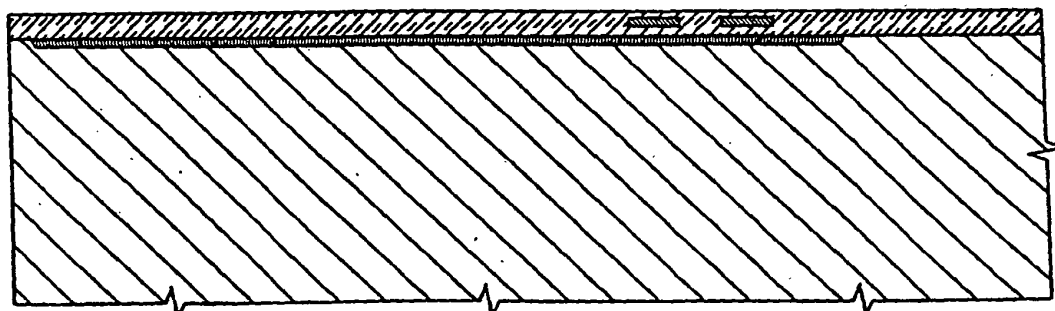
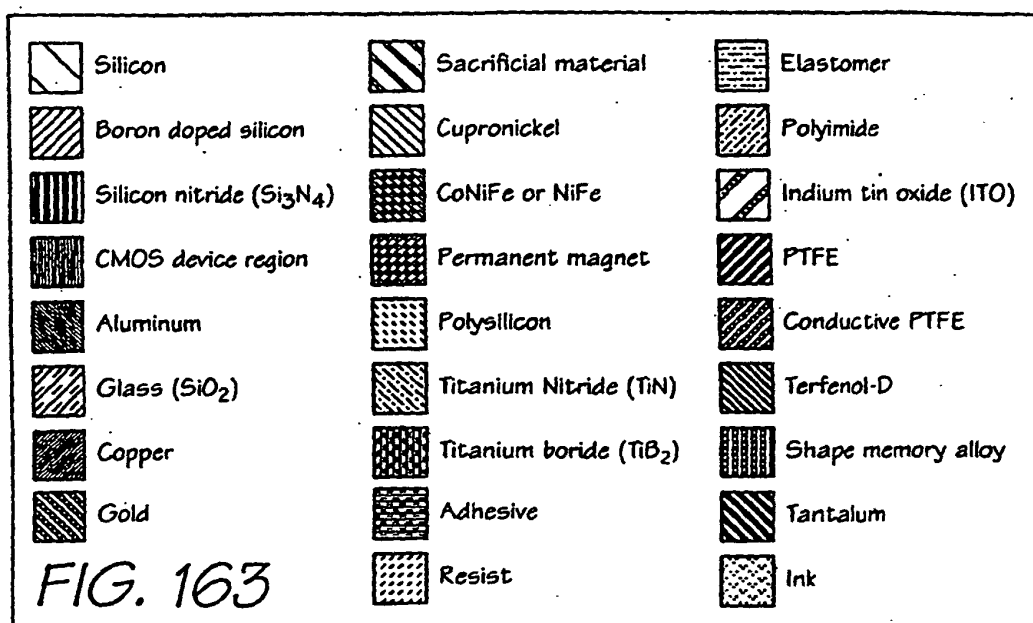


FIG. 164

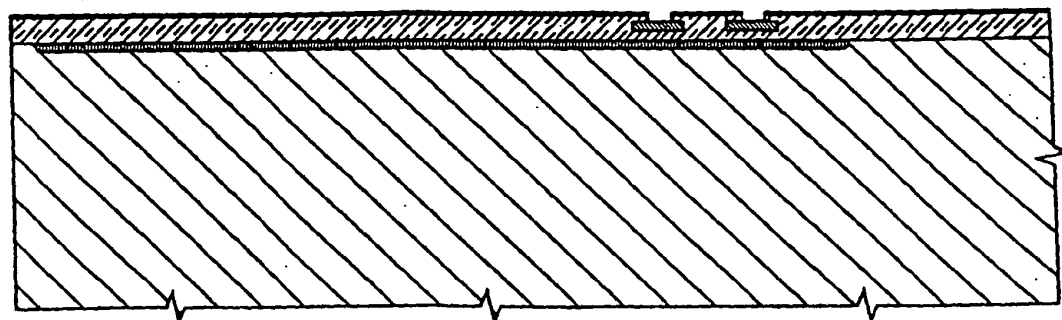


FIG. 165

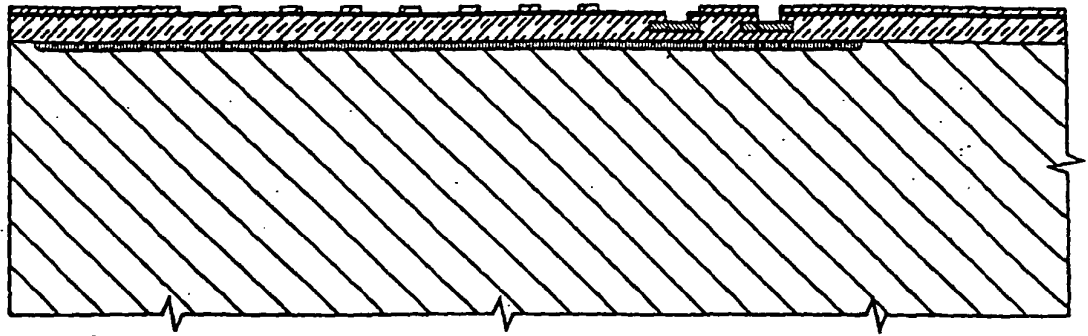


FIG. 166

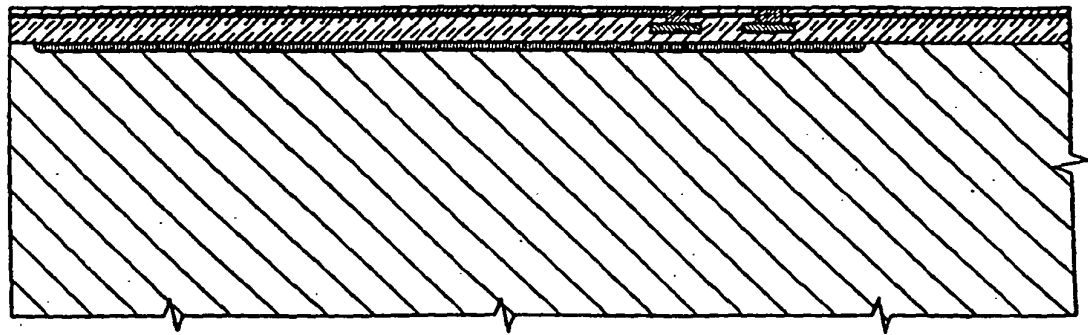


FIG. 167

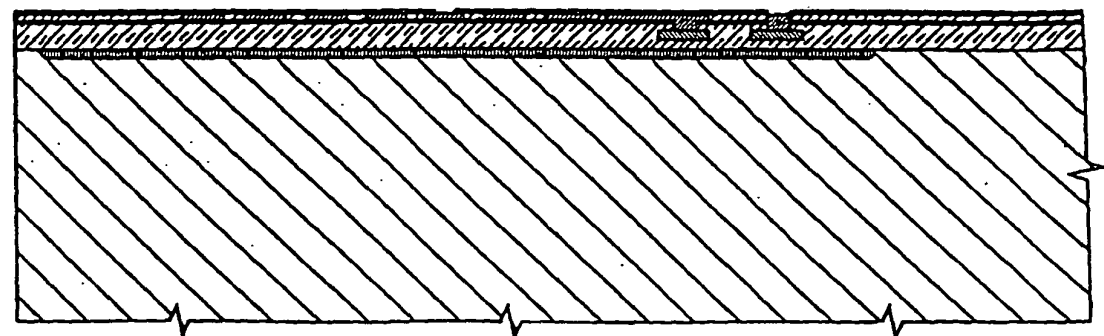


FIG. 168

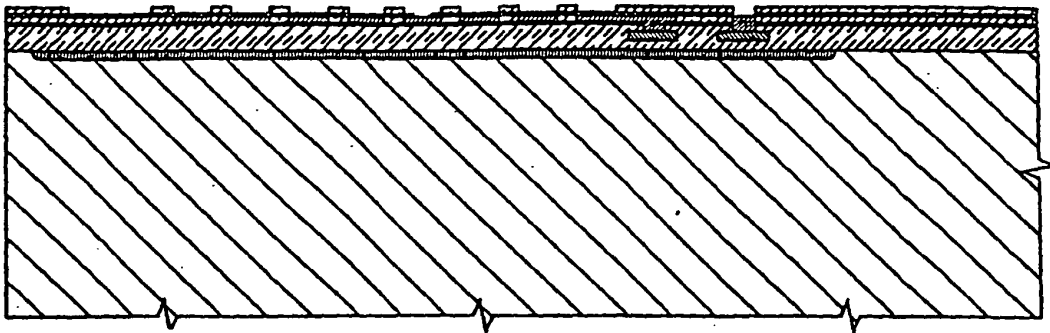


FIG. 169

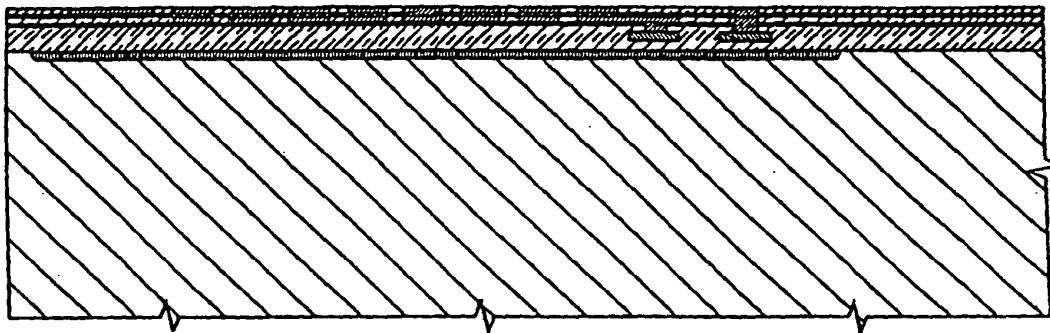


FIG. 170

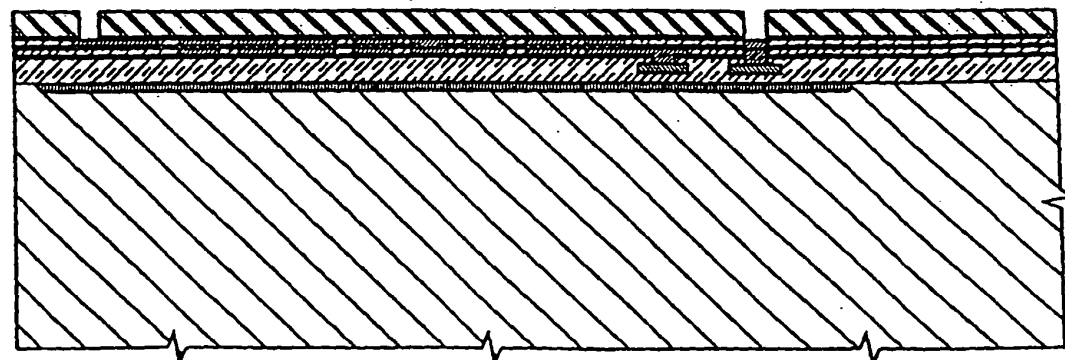


FIG. 171

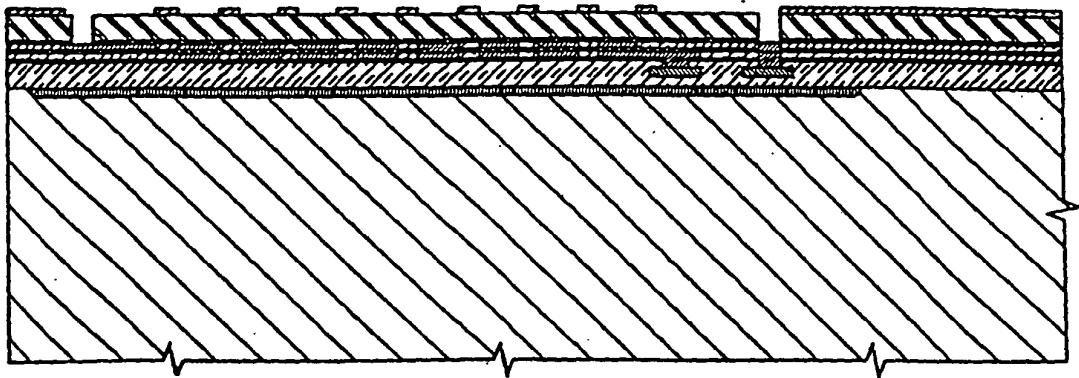


FIG. 172

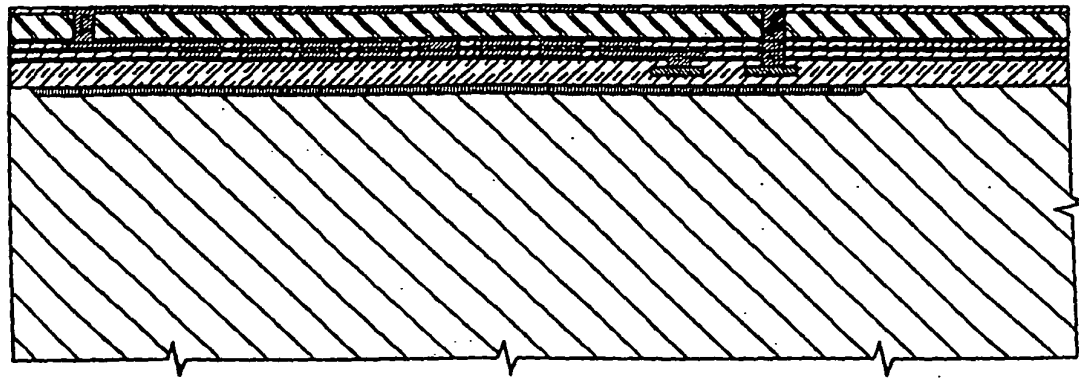


FIG. 173

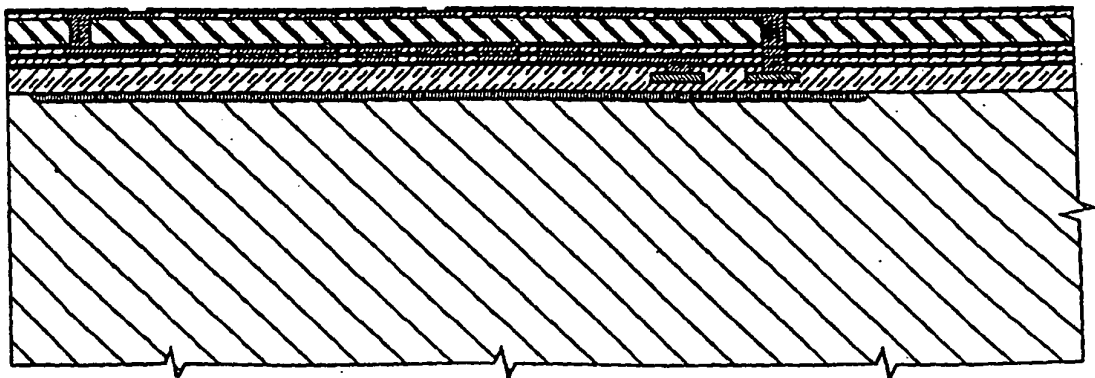


FIG. 174

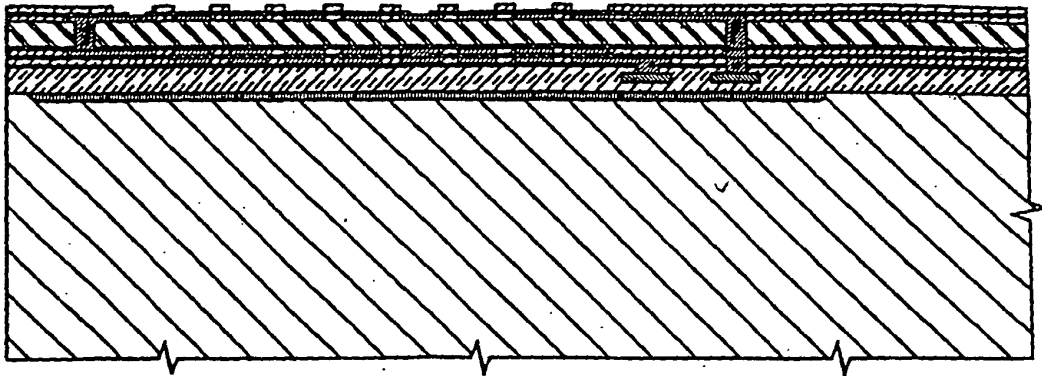


FIG. 175

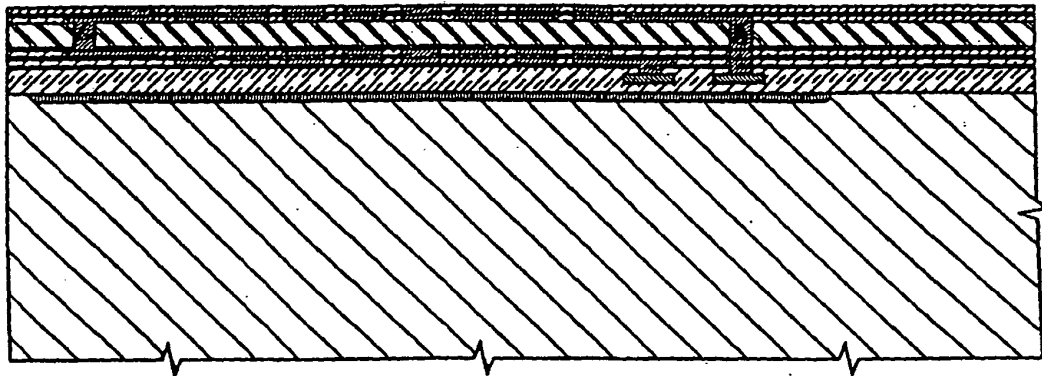


FIG. 176

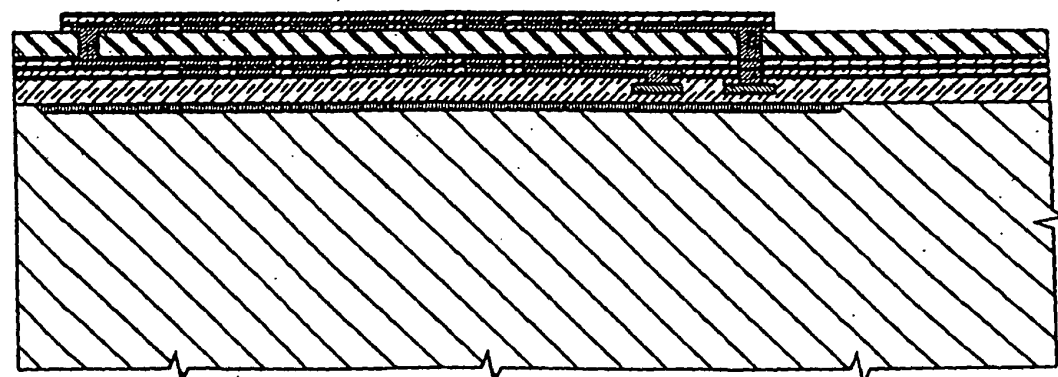


FIG. 177

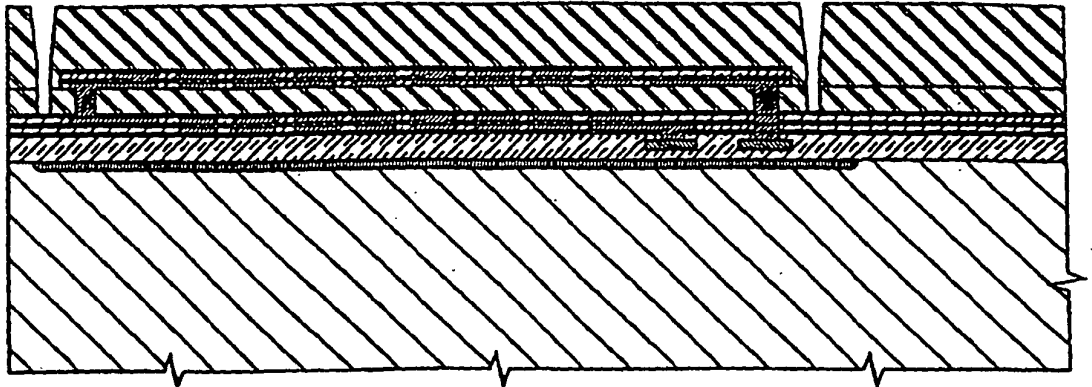


FIG. 178

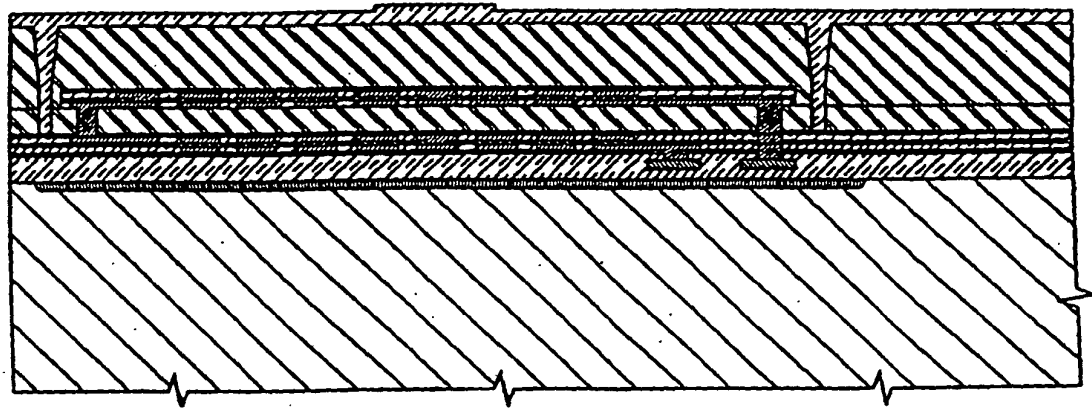


FIG. 179

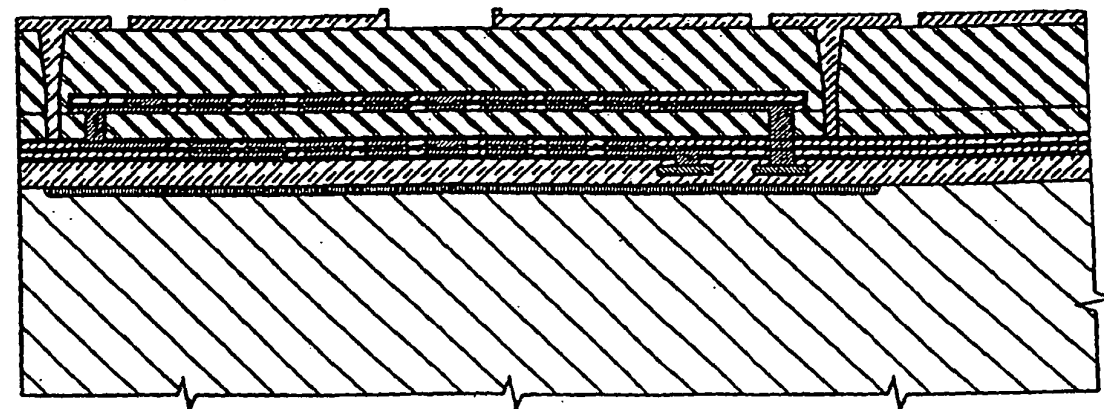


FIG. 180

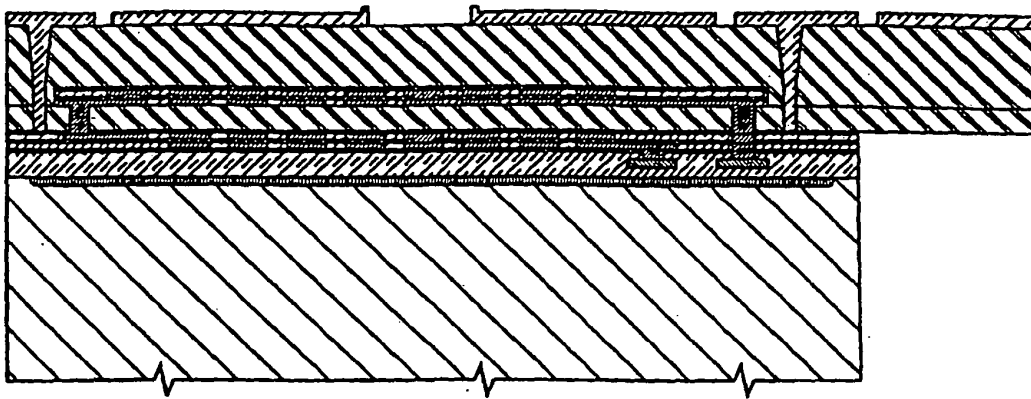


FIG. 181

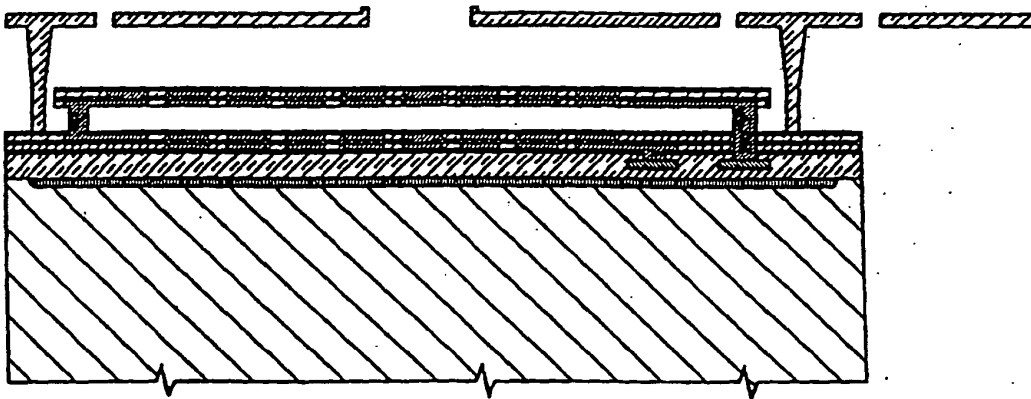


FIG. 182

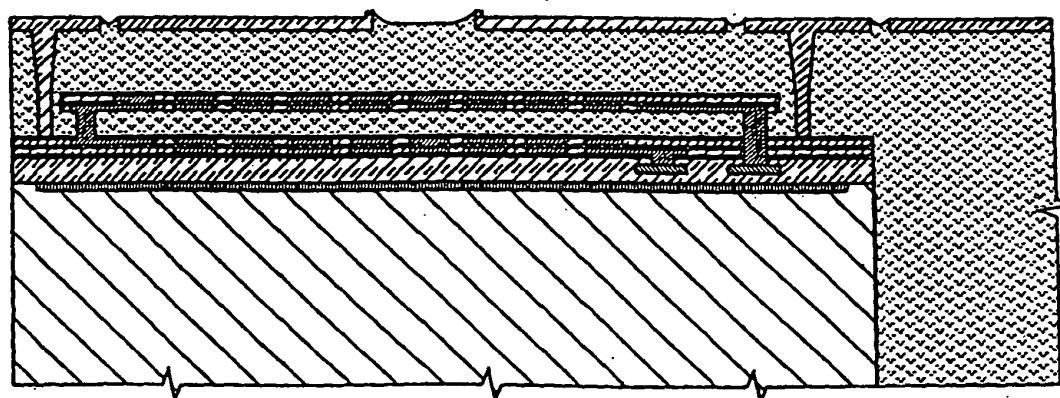


FIG. 183