

Electrohydrodynamic print head with ink pinning

Technical Field

5

The invention relates to an electrohydrodynamic print head and to a method for manufacturing the same.

Background Art

10

WO 2016/169956 describes an electrohydrodynamic print head having a nozzle carrier with a plurality of nozzles. It is designed to eject ink along an ejection direction.

15

Disclosure of the Invention

The problem to be solved by the present invention is to provide a specific print head of this type and a method for its manufacture.

20

This problem is solved by the print head of claim 1.

Accordingly, the print head may comprise at least the following elements:

- A nozzle carrier: This is a substrate on which the nozzles are arranged.

25

- A plurality of nozzles arranged on the carrier. The nozzles form the locations from where the ink is ejected.

- A plurality of ejection electrodes associated with the nozzles and located on the front side of the nozzles: The ejection electrodes are used to e.g. individually eject ink from their associated nozzles.

30

The print head comprises at least one multilayer structure with a bottom layer, a top layer, and at least one intermediate layer between the bottom layer and the top layer. The intermediate layer(s) form(s) walls extending between the bottom layer and the top layer. A plurality of cavities are located in the intermediate layer between the bottom layer and said top layer.

35

The walls may form at least part of the walls of the cavities.

Advantageously, at least part of the cavities, in particular a majority of the cavities, are closed cavities, i.e. they are closed on all sides, in particular by the

walls and by the bottom and the top layers. This aspect of the invention is based on the understanding that such cavities have applications other than as ducts. In particular, they can be used to reduce mechanical stress and/or to shape electric fields.

In one embodiment, the walls form a honeycomb structure between
5 the bottom layer and the top layer, i.e. a hexagonal pattern. Such a structure is found to reduce the mechanical stress.

In an important aspect of the invention, at least some of the cavities are arranged between different electrodes of the print head or between an electrode and an ink retainer of the print head. In this context, “different electrodes” are advantageously electrodes that, in operation of the print head, may carry different voltages.
10 This design improves the ability of the print head to better withstand the effects of the electrical fields.

Advantageously, the different electrodes are separated from the cavity or cavities by one or more solid dielectric layers. These layers help preventing an
15 electric breakdown between the electrodes.

The electrodes may be mounted to the bottom layer and/or the top layer of the multilayer structure, in particular with one electrode mounted to the bottom layer and the other electrode mounted to the top layer.

Advantageously, the electrodes are embedded into the bottom layer
20 and/or into the top layer, with the bottom layer and/or top layer forming dielectric solid layers covering the electrodes from the bottom and top sides.

The print head may further comprise guard electrodes arranged at a level behind the ejection electrodes. In this context, “at a level behind the ejection electrodes” indicates that the guard electrodes are closer to the nozzle carrier than the
25 ejection electrodes. Such guard electrodes can be used reduce the electric field strengths behind them, e.g. in order to reduce the fields at structures retaining (pinning) the ink.

In this case, at a given nozzle, at least some of the cavities may be arranged between the guard electrode and the ejection electrode, thereby reducing the
30 risk of electrical breakdown between the ejection electrode and the guard electrode.

The print head may further comprise at least one shielding electrode arranged at a level in front of the ejection electrodes. In this context, “at a level in front of the ejection electrodes” indicates that the ejection electrode is closer the nozzle carrier than the shield electrode. Such shield electrode(s) can be used to control
35 the field between the print head and the target.

In this case, at a given nozzle, at least some of the cavities may be arranged between the ejection electrode and the shielding electrode, thereby reducing

the risk of electrical breakdown between the ejection electrode and the shielding electrode.

As mentioned, the print head has a nozzle carrier to which the nozzles are mounted. In one embodiment, the nozzle carrier may comprise said multilayer structure (or if there are several such multilayer structures, then at least one of them).

In an advantageous design, the nozzle carrier comprises at least the following parts:

- A front layer: The nozzles are mounted to the front side of the front layer.

- A backing layer located at the back side of the front layer.

Electrical vias connected to the ejection electrodes may extend through the front layer and the backing layer. They feed voltages to the ejection electrodes.

In addition, ink feed ducts are arranged (at least) in the front layer.

In this case, the front layer may comprise the intermediate layer (or if there are several such multilayer structures, then at least one of them). This allows to form thick ink ducts without creating undue mechanical strain in the print head.

The print head may comprise a support structure supporting the ejection electrodes on the nozzle carrier, wherein the support structure comprises a plurality of support elements arranged between the nozzles. In this case, the support structure advantageously comprises at least the intermediate layer of the multilayer structure (or if there are several such multilayer structures, then at least one of them).

In this case, the print head may further comprise a plurality of ink retainers arranged between the nozzles and the support elements. The ink retainers prevent ink from reaching the support elements and wetting them. Along the ejection direction, the front surfaces of the ink retainers are located at a level behind (i.e. closer to the nozzle carrier) the front ends of the nozzles, i.e. along the ejection direction the ink retainers are set back in respect to the projections.

The method for manufacturing the print head advantageously comprises at least the following steps:

- Applying a material layer on said bottom layer: This material layer will later form at least part of the intermediate layer. The material may e.g. be a permanent photoresist like SU8.

- Removing part of the material layer: This leaves the walls in place and forms the cavities.

- Applying the top layer above the material layer.

Brief Description of the Drawings

5 The invention will be better understood and objects other than those set forth above will become apparent when consideration is given to the following detailed description thereof. Such description makes reference to the annexed drawings, wherein:

10 Fig. 1 shows a partially sectional view of a print head and of the target,

Fig. 2 is a vertical sectional view through a first embodiment of a nozzle,

Fig. 3 is a horizontal sectional view along line A-A of Fig. 2,

15 Fig. 4 is a horizontal sectional view along line B-B of Fig. 2,

Fig. 5 is a horizontal sectional view along line C-C of Fig. 2,

Fig. 6 shows some alternative nozzle tip designs in addition to the cross-shaped design of Fig. 5,

Fig. 7 is a horizontal sectional view along line D-D of Fig. 2,

20 Fig. 8 is a horizontal sectional view along line E-E of Fig. 2,

Fig. 9 is a vertical sectional view through a second embodiment of a nozzle,

Fig. 10 is a horizontal sectional view along line A-A of Fig. 9,

Fig. 11 is a vertical sectional view through a third embodiment of a

25 nozzle,

Fig. 12 is a vertical sectional view through a fourth embodiment of a nozzle, which basically corresponds to the first embodiment but illustrates the design of the nozzle support,

Fig. 13 is a horizontal sectional view along line A-A of Fig. 12,

30 Fig. 14 is a horizontal sectional view along line B-B of Fig. 12,

Fig. 15 is a horizontal sectional view along line C-C of Fig. 12,

Fig. 16 is a horizontal sectional view along line D-D of Fig. 12,

Fig. 17 is a vertical sectional illustrating two possible via designs for wiring of the electrodes,

35 Fig. 18 illustrates a multilayer honeycomb structure,

Fig. 19 shows a design of the walls of the intermediate layer,

Fig. 20 shows a vertical sectional view of an electrode with an embodiment of the dielectric layers surrounding it,

Fig. 21 is a vertical section view of an embodiment without ink retainer.

5

Note: While the ejection direction X in Fig. 1 points downwards, with the target being located below the print head, the ejection direction X in all other figures depicting vertical sectional views points upwards, i.e. Fig. 1 is rotated by 180° in respect to all other figures showing sections parallel to the ejection direction. The direction in those figures is rather based on how manufacturing progresses, i.e. lower layers are manufactured ahead of top layers.

10

Modes for Carrying Out the Invention

15

Definitions

“Forward” defines the direction into which the print head is designed to eject ink. For example, the ejection electrodes are forward from the nozzles.

20

“Backward” defines the opposite direction. For example, the nozzles are arranged backward from the ejection electrodes.

“At the front” and “at the back” are understood to designate a location at levels forward from or backward from something else.

“Front” and “back” are the forward and backward sides.

25

Properties “at a given nozzle” are advantageously understood as properties that are true for a majority, in particular for least at 90%, of the nozzles. For example, if it is said that “at a given nozzle, the guard electrode is arranged between the ejection electrode and the ink retainer”, this advantageously means that this is true for a majority of the nozzles, in particular for at least 90% of them. It may e.g. be that there are some nozzles that do not have ejection electrodes and/or guard electrodes, such as nozzles at the edges of the print head and/or unused nozzles.

30

The ejection direction X of the print head defines the “vertical” upwards direction, i.e. the print head is, by definition, designed to eject ink upwards. (In operation, it may, of course, be under any angle to the direction of gravity.) Hence, definitions such as “above” and “below” are to be understood in reference to this definition of “vertical”.

35

“Horizontal” is any direction perpendicular to the vertical direction.

“Lateral” designates something that is horizontal from something else.

Print Head

5 Fig. 1 shows a schematic sectional view of an embodiment of the print head 1. It is depicted above a target 2 and it is structured to eject ink along an ejection direction X onto the target.

The print head comprises a plurality of nozzles 4 located at the front side of a nozzle carrier 6. The nozzles 4 may be arranged in a one- or two-dimen-
10 sional array.

The print head has a plurality of ejection electrodes (not shown in Fig. 1) for ejecting ink from the nozzles 4 and optional further electrodes arranged on a support structure 8, the design of which is described in more detail below. Further electrodes may be provided in electrical contact with the ink to set the ink to a defined
15 electrical potential.

Nozzle carrier 6 comprises a front layer 10, with the nozzles 4 being mounted to the front side of front layer 10 and forming projections thereon. It also comprises a backing layer 12 located at the back side of front layer 10.

The internal structure of front layer 10 is not shown in Fig. 1 and
20 will be described in more detail below. It may e.g. be of a dielectric, in particular a polymer.

Backing layer 12 may e.g. be an insulated semiconductor material or it may be a dielectric. Advantageously, backing layer 12 is, at least partially, of glass.

25 Electrical vias 14 are connected to the ejection electrodes and extend through front layer 10 and the backing layer 12 for connecting the ejection electrodes to a voltage supply 17. Advantageously, there is at least one via 14 for each nozzle 4. Further vias may be provided to connect other electrodes to voltage supply 17.

30 Ink ducts 15, 16 supply ink to the nozzles 4 and (optionally) recycle ink back from the nozzles 4. They are located, in part, in front layer 10 and they extend through peripheral regions of backing layer 12. Their design is described in more detail below.

Fig. 1 shows an embodiment of the print head that has supply ducts
35 15 as well as suction ducts 16 for the ink.

At least one pump 18 and/or another pressure source or vacuum source is provided to supply ink to the supply ducts 15 and, if there are suction ducts, to retrieve ink from the suction ducts 16.

Advantageously, the print head comprises a first pressure control 20 for generating a first defined pressure p_1 at the input of the supply ducts 15, e.g. in a reservoir tank 22.

The ink is supplied through an optional filter 24 and the supply ducts 15 to the nozzles 4.

If there are suction ducts 16, they are connected to a suction system, which may comprise a second pressure control 26 for generating a second defined pressure p_2 at the exit of the suction ducts 16, e.g. in a suction tank 28. The suction system may also comprise a pump. This may in particular be pump 18 as mentioned above, in which case pump 18 acts as a circulating pump.

A suitable pump design is e.g. shown in US 6631983.

As further shown in Fig. 1, the print head may comprise a circuit carrier 30, such as a PCB, arranged at the back side of nozzle carrier 6.

An optional interposer layer 32 may be provided between circuit carrier 30 and nozzle carrier 6 for matching a denser resolution of the vias 14 to the circuit resolution of circuit carrier 30. Such interposer layers are e.g. used in flip-chip designs where semiconductor chips are applied to PCBs.

Circuit carrier 30 carries control circuitry 33, which may e.g. implement at least part of voltage supply 17, such as the driver stage of such a voltage supply, which connects voltage sources to the various electrodes of the print head.

In the shown embodiment, the ink ducts 15, 16 extend through interposer layer 32 (if present) as well as circuit carrier 30.

If the vias 14 have a large enough mutual spacing (e.g. larger than 0.4 mm), they may directly interface with circuit carrier 30 without an interposer layer 32.

Advantageously, target 2 is arranged on an acceleration electrode, which is connected to voltage supply 17 to generate an accelerating electrical field between print head 1 and target 2.

The pressure controls 20, 26 can be used to maintain pressures as described in the section Operating the Print Head below. Advantageously, they allow to separately adjust the pressures in the supply ducts 15 as well as in the pressure ducts 16.

Nozzle Design 1

Figs. 2 – 8 show a first embodiment of a nozzle 4 and the surrounding elements. (As mentioned above, in contrast to Fig. 1, the ejection direction X in Fig. 2 points upwards.)

5 As can be seen from Fig. 2, nozzle 4 forms a projection on the front side 36 of nozzle carrier 6, e.g. on the front side of its front layer 10. It is located at an exit passage 5 through which ink can be ejected towards target 2.

Fig. 2 also shows the various electrodes that may be associated with the nozzles 4.

10 The ejection electrode 38 is located on the front side of the nozzle 4. In the embodiment of Fig. 2 and 7, it is annular with a central opening 39 for the passage of the ink. It is connected to one of the vias 14, which extends through support structure 8 and nozzle carrier 6.

Figs. 3 and 4 show two possible implementation of the vias 14. On the right side, under reference number 14, a hollow implementation is shown, where the vias are formed as a metallic coating 14a within a dielectric tube 14b extending along the ejection direction and surrounding a central duct 14c, which may also be used as a ventilation duct for feeding gas to/from the region between the print head and the target. This type of structure can e.g. be formed by

- 20 a) Forming the tube 14b together with the honeycomb structure as described below, and
b) Forming the metallic coating 14a within tube 14b e.g. by sputtering.

The alternative design, shown under reference number 14', comprises a solid metal core 14'a within a dielectric tube 14'b. Tube 14'b can again be formed together with the honeycomb structure as described below, and metallic core 14'a can e.g. be formed by means of electro plating.

25 The alternative via designs 14, 14' are also shown in Fig. 17. The hollow via design 14 is depicted for connecting the shielding electrode 40 while the filled via design 14' is depicted for the ejection electrode 38 (which is not visible in Fig. 17). Note: Only the metal parts are shown as hatched regions in Fig. 17 while other cross-sectioned parts are not hatched.

Typically, a single print head will only use one design of vias, with the two different types in Figs. 3, 4, and 17 shown for illustration purposes only.

35 Turning to Fig. 2 and 8, a shielding electrode 40 may be located at the front side of and at a distance from the ejection electrodes 38, i.e. the ejection

electrodes 38 are closer to nozzle carrier 6 than the shielding electrode 40. Advantageously, there is one continuous shielding electrode 40 extending over the front of print head 1, but there may also be several such shielding electrodes.

If several shielding electrodes are used, they may be applied to different potentials, e.g. by applying a voltage gradient by means of a voltage divider, which e.g. allows to gradually deflect the ink over a cross section of the print head.

Shielding electrode 40 is provided to control the field between print head 1 and target 2. For each nozzle 4, an opening 41 in shielding electrode 40 allows for the passage of the ink.

As shown in Figs. 2 and 5, a guard electrode 42 may be located behind and at a distance from ejection electrode 38 but in front of and at a distance from nozzle carrier 6. As shown in Figs. 2 and 5, it may again be annular. Alternatively, it may also extend over several nozzles.

An opening 43 in guard electrode 42 above nozzle 4 allows for the passage of the ink.

The function of guard electrode 42 is described below.

Nozzle 4 of this embodiment comprises a tip section 46, a shaft section 48, and a base section 50, 52, with tip section 46 arranged in front of shaft section 48, and base section 50, 52 (Figs. 2, 3) arranged behind shaft section 48.

The shown nozzle design relies on the ink wetting the lateral surface of nozzle 4 and not passing through a central channel of nozzle 4 (as it is e.g. known from WO 2016/169956), but the latter could be used as well.

If nozzle 4 has a central channel, e.g. if exit duct 60 extends all the way to the tip of the nozzle, the nozzle 4 is advantageously still operated such that ink not only wets the top of the nozzle but also its lateral outer sides. By making sure that ink covers the outside of all nozzles, all nozzles provide the same ink geometry to the ejection electrodes, which allows to achieve a more uniform ink ejection over the whole print head.

To facilitate a good flow of ink along nozzle 4 into ejection direction X, nozzle 4 advantageously has at least one groove running along ejection direction X on its lateral surface, i.e. on the surface extending along ejection direction X. This groove(s) run(s) along at least part of the length of nozzle 4.

This can e.g. be seen in Fig. 5, where tip section 46 is shown to be cross-shaped (with four recesses 46a formed between the arms of the cross), and where shaft section 48 forms two grooves 48a.

Fig. 6 shows alternative designs of tip section 46:

(a) is a tip section 46 that has a convex lateral surface and is e.g. a cylinder without a groove – this is the presently preferred design because it generates a good meniscus for the ink to be ejected from;

(b) is a tip section 46 that forms two lateral grooves 46a;

5 (c) is a tip section that forms an axial canal 46c.

Base section 50, 52 connects tip section 46 and shaft section 48 to nozzle carrier 6. It also contains the duct(s) for feeding ink to the nozzle. This is best seen in Figs. 2, 3, and 4.

10 In particular, in the shown embodiment, base section 50, 52 comprises a bottom sublayer 52 and a top sublayer 50. Bottom sublayer 52 has a central opening 54 communicating with the end of a supply duct section 15a that feeds ink to nozzle 4. One or more radial transversal exit ducts 56 extend, transversally to ejection direction X, outwards from central opening 54 to a first annular duct 58.

In Fig. 2, the flow of the ink in the duct are depicted by arrows.

15 Top sublayer 50 may also form an axial exit duct 60 extending towards the tip of the nozzle and connecting supply duct section 15a to the grooves 48a (Fig. 5) of shaft section 48, thereby guiding ink directly up towards tip section 46.

Top sublayer 50 may be surrounded by a second annular duct 62 aligned with first annular duct 58 surrounding nozzle 4.

20 Nozzle 4 is surrounded by an ink retainer 66, whose purpose is to retain the ink laterally. Annular duct 62 is located, in radial direction, between ink retainer 66 and nozzle 4, thereby communicating with a region 64 between nozzle 4 and ink retainer 66.

25 The front surface 68 of ink retainer 66 (i.e. the front-facing surface closest to the ejection electrode 38) is set back, along ejection direction X, in respect to the front end 70 of nozzle 4. Hence, when there is ink in region 64, the surface of the ink forms an ascending slope, as shown by the dash-dotted lines, towards the tip of nozzle 4, making sure that the tip is the location where the ink is closest to ejection electrode 38, thereby forming a defined point to launch the ink from.

30 The main function of ink retainer 66 is to pin the ink, i.e. to keep the ink away from the vertical parts of support structure 8, i.e. to prevent it from climbing up and forming a pool that might submerge the nozzle.

This function is implemented by a combination of one or more of the following features:

35 a) Ink retainer 66 is provided with a hydrophobic and/or oleophobic surface, e.g. by a hydrophobic and/or oleophobic coating 73, shown with a thick, black line in Fig. 2. For example, the surface can be formed, at least in part, of Teflon

and/or PTFE, which are hydrophobic and oleophobic. Depending on the scope of inks to be used, it may also be only hydrophobic (e.g. HMDS, i.e. Bis(trimethylsilyl)amine) or only be oleophobic (e.g. based on polymers). In particular, the surface of ink 66 retainer is advantageously more hydrophobic and/or oleophobic than a surface of nozzle 4.

b) Ink retainer 66 forms a ledge 66a facing away from the nozzle 4 closest to it, which makes it hard for the ink to creep around it. In other words, when seen from the nozzle, the ledge extends outwards, forming an “undercut” 66b.

c) Ink retainer 66 is located in a region where electric fields are low. Since strong electric fields tend to decrease the surface tension of the ink, this design reduces the risk of the ink wetting its way around the ink retainer. In the shown embodiment, the guard electrode 42 associated with nozzle 4 is arranged between ejection electrode 38 and ink retainer 66. In this context, “between” advantageously means that guard electrode 42 intersects, and advantageously divides in two, the volume of space between ejection electrode 38 and ink retainer 66.

It must be noted that ink retainer 66 is not the only means for retaining the ink laterally, i.e. for preventing the ink to reach the closest support element. Alternatively or in addition thereto, the ink suction ducts 16 may be used to remove any ink that might reach the support elements. This is described in more detail in the section Operating the Print Head.

Guard electrode 42 is connected to voltage supply 17, e.g. by means of vias 14' or 14, and it may be set, during operation, to a potential that is closer to the potential of ink retainer 66 (i.e. of the ink) than to the (maximum) potential of the ejection electrodes. In particular, voltage supply 17 may be adapted to keep guard electrode 42 at the same potential as ink retainer 66. This allows to keep the electrical field at ink retainer 66 very low.

As shown in Fig. 2, guard electrode 42 is advantageously arranged at the same “height” (with the vertical direction defined by the ejection direction X) as the front end 70 of nozzle 4, e.g. within an accuracy of 25% of the vertical distance between ejection electrode 38 and the front end 70 of nozzle 4. This provides for a good shielding of the ink below the tip of nozzle 4 while still strongly exposing the tip to the field of ejection electrode 38.

As can be seen in Fig. 2, there is an air-filled cavity 71 forming a gap between guard electrode 42 and ink retainer 66, which prevents the ink from reaching guard electrode 42.

To laterally retain the ink in region 64, ink retainer 66 is advantageously arranged on the front side 36 of nozzle carrier 6 and projects from it. In the

embodiment of Figs. 2 – 4, it comprises a first ring 72 mounted to front surface 36 of nozzle carrier 6 and a second ring 74 mounted to the front side of first ring 72. Second ring 74 forms the ledge 66a mentioned above.

5 *Ink Suction*

As mentioned above, in the embodiment of Figs. 1 and 2, suction ducts 16 are provided to retrieve ink from the nozzles 4. This allows to maintain a flow of fresh ink at a given nozzle.

10 In that case, at a given nozzle, the closest ink retainer 66 advantageously surrounds not only nozzle 4 and the end section 15a of the supply duct but also the end of the end section 16a of suction duct 16. Hence, the two ducts can be used to control the flow of ink towards a nozzle and back from it.

The pressure at the supply ducts 15 and the suction ducts 16 is adjusted to keep the ink in region 64 somewhere e.g. between an upper level 64a and a lower level 64b as shown in Fig. 2. Advantageously, and as described in more detail
15 in the section “Operating the Print Head” below, the ink is kept at the lower level 64b.

For a good lateral restriction of the ink, each nozzle 4 is advantageously surrounded by the opening or openings of one or more suction ducts. This may e.g. be a single annular opening (such as formed by annular opening 62 of Fig.
20 2), or it may be an annular series of suction openings. This opening or these openings is/are arranged between the nozzle and the support elements 78 next to it.

Support Structure

25 As mentioned, a support structure 8 is provided for connecting the various electrodes 38, 40, 42 to nozzle carrier 6. It is arranged on front side 36 of nozzle carrier 6.

Support structure 8 comprises a plurality of support elements 76, 78 arranged between the nozzles 4.

30 Ink retainer 66 is advantageously designed to prevent ink from reaching these support elements 76, 78 and to prevent it from wetting them, thereby reducing the tendency of the ink to submerge the nozzles.

Support structure 8 advantageously comprises at least one electrode carrier layer. In the embodiment of Fig. 2, there are three such layers 80, 82, 84. Each such electrode carrier layer comprises at least one electrode 38, 40, 42 and may extend parallel to top surface 36.
35

Typically, the electrode 38, 40, 42 is embedded within its electrode carrier layer 80, 82, 84 and covered on its front and back side by at least one dielectric sublayer 80a, 80b or 82a, 82b or 84a, 84b.

At least part of the support elements are formed by vertical walls 76 forming a honeycomb structure, see Fig. 3. Each such honeycomb structure is part of a multilayer structure which is used in various parts of the print head and is described in more details below.

In addition or alternatively to the walls 76 forming honeycomb structures, the support elements comprise, in the shown embodiment, a vertical wall 78 surrounding exit passage 5 of each nozzle 4. Wall 78 may e.g. be a cylindrical wall, but it may also e.g. be polygonal. It is advantageously centered on nozzle 4.

In another embodiment, walls 78 may also be dispensed with, and the walls around exit passage 5 may be formed by the walls 76 of the honeycomb structure. In this case, the honeycomb structure needs to be aligned with the nozzles.

In yet another embodiment, several nozzles may be surrounded by a single wall 78.

In the embodiment shown here, the support elements 76 and/or 78 are provided between each of the electrode carrier layers 80, 82, 84 as well as between the backmost electrode carrier layer 80a and nozzle carrier 6. They may, however, also only be provided between a subset of these structures.

As can best be seen from Fig. 2, there is a first recess located between nozzle 4 and its ink retainer 66, which is formed by the annular first and second annular duct 58, 62. It provides a volume to receive at least part of ink pool 64. Along ejection direction X, the bottom of first recess 58, 62 is at the back in respect to (i.e. is closer to nozzle carrier 6 than) the front surface 68 of ink retainer 66.

In the shown embodiment, there is a second recess 86 located between ink retainer 66 and the closest support element 78. It provides room for ledge 66a and/or makes it harder for the ink to reach support element 78. Along ejection direction X, the bottom of recess 86 is at the back in respect to (i.e. is closer to nozzle carrier 6 than) the front surface 68 of ink retainer 66.

Nozzle Design 2

Figs. 9 and 10 show a second embodiment of a nozzle design. It primarily differs from the first one in that there is only an ink supply duct 15 (with its end section 15a shown in Fig. 10) but no suction duct for the nozzle.

Further, there is no recess between nozzle 4 and ink retainer 66. Rather, ink retainer 66 is laterally arranged on nozzle 4 with its front surface 68 at a distance from front end (tip) 70 of nozzle 4.

In other words, its front surface 68 is set back with respect to front end 70 of nozzle 4 in order to form an ascending slope for the ink in region 64 and reducing the risk of submerging the nozzle.

Advantageously, ink retainer 66 is mounted “low” on the nozzle 4 to make submerging the nozzle less probable. In particular, front surface 68 of ink retainer 66 is closer to the front size 36 of nozzle carrier 6 than to front end 70 of nozzle 4.

As can be seen, in this embodiment, ink retainer 66 is formed by the sublayer 52 of the base section of nozzle 4.

Nozzle Design 3

Fig. 11 shows a third embodiment of a nozzle design. It primarily differs from the second one in that it has no guard electrode. To keep the electrical field at the location of ink retainer 66 low, ink retainer 66 is located far back.

In particular, as shown in Fig. 11, the distance d' , along ejection direction X, between front surface 68 of ink retainer 66 and front end 70 of nozzle 4 is large.

Quantitatively, if d designates the distance, along ejection direction X, between ejection electrode 38 and the front end 70 of nozzle 4, the following condition is advantageously maintained:

$$d' > k \cdot d$$

with k being at least 0.5, in particular at least 1.0.

Nozzle Design Without Ink Retainer

In the embodiments shown so far, nozzle 4 was surrounded by the ink retainer 66 that projects up from top surface 36 of nozzle carrier 6. However, using ink suction allows to dispense with such an ink retainer. This is illustrated in Fig. 21, which shows an embodiment basically corresponding to the one of Fig. 2 but without an ink retainer. Hence, the layers forming the base sections 50, 52 of the embodiment of Fig. 2 may be dispensed with.

In this embodiment, the ink is retained around nozzle 4 by being sucked into the end section(s) 16a of ink suction ducts 16 that surround the nozzle.

In one embodiment, a single, annular (or e.g. hexagonal or otherwise closed-loop) end section 16a of the suction ducts 16 may be arranged around
5 nozzle 4.

In another embodiment, a plurality of individual end sections 16a may be provided, closely spaced and surrounding nozzle 4, e.g. arranged along a circle or another closed loop.

In this embodiment, guard electrode 42 may still be useful because
10 it reduces the tendency of the ink to spread along surface 36 of nozzle carrier 6.

In the embodiment shown, exit duct 60 extends all the way to the top 70 of the nozzle. Hence, ink flows axially through the nozzle. Advantageously, the pressure in exit duct 60 is selected such that the ink overflows the nozzle and flows down along its lateral side walls. From there, it arrives at the end section(s) 16a
15 of the suction ducts 16 and is carried off. This provides for a continuous ink exchange in the nozzle.

In another embodiment, the ink may be guided up along the outer surface of the nozzles, e.g. in grooves as shown in the embodiment of Figs. 2 – 5, and the ink can be suctioned off from the end section 16a, e.g. through an axial opening in
20 the nozzle.

Optionally, however, the designs of this section may also be combined with e.g. a simple ink retainer 66 (as indicated in dotted lines) surrounding the end section(s) 16a of the suction ducts 16.

25 *Nozzle Carrier*

Figs. 12 – 16 show a possible design of nozzle carrier 6. It is to be noted that Figs. 13 – 15 are at a reduced scale as compared to Fig. 12 in order to illustrate how neighboring nozzles may be interconnected by supply ducts and suction ducts, and Fig. 16 is shown at an even more reduced scale illustrating a whole cross
30 section of the print head at the level of backing layer 12.

These figures show the nozzle of Fig. 2, but similar nozzle carriers can be used for different nozzle designs, such as for the designs of Figs. 9 and 11.

As mentioned above, nozzle carrier 6 comprises a front layer 10, with the nozzles 4 being mounted to the front side 36 thereof, as well as a backing layer 12 located at the back side of front layer 10. Front layer 10 as well as backing
35 layer 12 may in turn be multi-layer-structures.

They are described in more detail in the following.

Front layer 10 consists of several sublayers 10a – 10d and forms at least part of the ducts 15, 16 for feeding ink to and, where applicable, from the nozzles.

In the embodiment of Fig. 12, front layer 10 comprises, in front-to-back order, sublayers 10a, 10b, 10c, and 10d for forming the ducts.

Sublayer 10a forms front surface 10a and comprises openings 15a, 16a for the supply ducts and (if needed) the suction ducts, respectively.

Sublayer 10b forms (if needed) horizontal sections 16b of the suction ducts as well as vertical sections 15b of the supply ducts.

As best seen in Fig. 13, the horizontal sections 16b of the suction ducts interconnect all or at least a plurality of the nozzles 4. In addition, between the ducts, sublayer 10b comprises vertical walls 90 forming honeycomb patterns similar to the ones in support structure 8. The regions of the honeycomb patterns may be separated from the ducts 16b and/or 15b by means of vertical separating walls 92.

Fig. 13 also shows the vias 14, 14' extending along ejection direction X through all of front layer 10.

The vertical sections 15b of the supply ducts are connected to vertical sections 15c of the supply ducts in sublayer 10c, see Fig. 14.

As shown in Fig. 15, sublayer 10d forms horizontal sections 15d of the supply ducts, interconnecting neighboring nozzles.

Again, sublayer 10d may comprise vertical walls 94 forming honeycomb patterns similar to the ones in support structure 8. The regions of the honeycomb patterns may be separated from the ducts 10d by means of vertical separating walls 96.

Fig. 15 also shows the vias 14, 14' extending along ejection direction X through all of front layer 10.

Fig. 16 shows a possible arrangement of electrical vias 14 (and 14'), the supply ducts 15 and the suction ducts 16 at the level of backing layer 12. Since the horizontal distribution of the ink ducts 14, 16 is implemented in front layer 10 above backing layer 12, the ink can be fed through one or a few, potentially large ink ducts arranged outside the convex hull 96 of the regular array of electrical vias 14, which simplifies the design of backing layer 12, i.e. no ink ducts extend through the backing layer 12 within the convex hull 96.

Instead of using a honeycomb structures in the sublayers 10b and/or 10d, solid layers may be used, e.g. of glass.

Honeycomb Multilayer Structures

As follows from the above, the print head shown here advantageously uses one or more honeycomb multilayer structures. One such multilayer structure 109 is illustrated in Figs. 18, 19. It has a bottom layer 110, a top layer 112, and at least one intermediate layer 114 between bottom layer 110 and top layer 102. Intermediate layer 114 forms walls 116 extending between bottom layer 110 and top layer 112. These walls form at least part of the walls of a plurality of cavities 118 in the intermediate layer 114 between bottom layer 110 and top layer 112.

The walls 114 advantageously form a honeycomb pattern.

Such a structure is found to reduce mechanical stress, in particular if the bottom or top layer 110, 112 is of a material different from intermediate layer 114 and/or if it is located close to or adjacent to another layer that is of a material different from intermediate layer 114.

Examples of such honeycomb multilayer structures in the examples above are the following:

- In Figs. 2, 11, 12: Front layer 10 or sublayer 10a is the “bottom layer” 110, layer 80 of support structure 8 is the “top layer” 112, and the walls 76 between them form the “intermediate layer” 114.

- In Figs. 2, 11, 12: Layer 80 of support structure is the “bottom layer” 110, layer 82 of support structure 8 is the “top layer” 112, and the walls 76 between them form the “intermediate layer” 114.

- In Figs. 2, 11, 12: Layer 82 of support structure is the “bottom layer” 110, layer 84 of support structure 8 is the “top layer” 102, and the walls 76 between them form the “intermediate layer” 114.

- In Figs. 12, 13: Sublayer 10c is the “bottom layer” 110, sublayer 10a is the “top layer” 112, and the walls 90 of sublayer 10b between them form the “intermediate layer” 114.

- In Figs. 12, 15: Backing layer 12 is the “bottom layer” 110, sublayer 10c is the “top layer” 112, and the walls 94 of sublayer 10d between them form the “intermediate layer” 114.

In the first three examples, support structure 8 comprises at least the intermediate layer 114 of the multilayer structure.

In the last two examples, nozzle carrier 6 comprises at least the intermediate layer 114 of the multilayer structure.

If the thickness t of intermediate layer 114 (see Fig. 18) is comparatively large, the stress reduction achieved by the multilayer structure is particularly

evident. Advantageously, the thickness t is larger than $1\text{ }\mu\text{m}$, in particular larger than $10\text{ }\mu\text{m}$.

Advantageously, intermediate layer 114 is a polymer layer, e.g. formed from an SU-8 layer after structuring. This type of layer can be manufactured and structured easily (see manufacturing information below), and if using it in a multilayer structure as shown reduces the stress as to compared to a solid layer of such a material.

Hence, advantageously, the print head comprises at least one layer of a material different from the intermediate layer, in particular a layer of semiconductor or glass.

The cavities 118 are advantageously closed cavities, i.e. they do not form part of the ink duct sections 15b or 16d in Figs. 15 and 13 nor do they communicate with the surrounding atmosphere.

If the walls 116 form a regular, repetitive pattern, homogeneity is improved and stress can further be decreased.

Advantageously, the walls 116 have a thickness m of less than 25% of the minimum diameter M of the cavities (see Fig. 19). This leads to a low content of solid material in the intermediate layer, further reducing mechanical stress. In this context, the thickness m is the extension of the walls 116 perpendicular to their surfaces. The diameter M of the cavities is the extension of the cavities 118 in a direction parallel to the bottom and top layers 110, 114.

For best strain removal, the minimum diameter M of the cavities 118 is advantageously larger than the thickness t of intermediate layer 114, i.e. $M > t$. Smaller cavities extending through intermediate layer 114 would generate higher mechanical stress in the intermediate layer.

The walls 116 extend advantageously perpendicular to bottom layer 110 and the top layer 112. This not only improves the mechanical stability against forces acting perpendicularly to the layers, but it also allows to form the walls by anisotropic material removal techniques, particularly by photolithography of a photo-active polymer.

It must be noted that the top layer and the bottom layer of the multilayer structures are parallel to each other.

The closed cavities 118 do not communicate with the ink ducts, i.e. they are not used for guiding ink through the print head. If the print head has ventilation ducts, the closed cavities 118 do not communicate with these ventilation ducts either.

The closed cavities 118 may be filled with air. Alternatively, they may be evacuated. Or they may be filled with a gas such as nitrogen. Advantageously, they may be filled with a gas having a high breakdown voltage, such as SF₆ or C₄F₈. The gas can be introduced by performing the respective manufacturing step
5 (see below) in a workspace having the desired gas composition.

Electrode Design

The print head is designed to withstand the high electric fields that occur during operation with minimum structural damage.

10 For this purpose, the electrodes 38, 40, 42 are arranged between solid dielectric layers 80a, 80b, 82a, 82b, 84a, 84b that border cavities. In the shown embodiments, such cavities are e.g. formed by the cavities 71, 71', 71'' below the electrode carrier layer 80, 82, 84 and/or by the cavities 118 formed by the walls 116.

At least some of the cavities may be closed cavities (i.e. enclosed by
15 walls on all sides, such as the cavities 118).

At least some of the cavities may be open cavities, in particular cavities communicating with and being adjacent to exit passage 5 of nozzle 4, such as the cavities 71, 71', 71'' of the embodiments above.

In such a design, the solid dielectric layers around the electrodes
20 typically are able to withstand higher fields than the gas in the cavities and also have higher relative permittivity ϵ , and they therefore prevent a total breakdown. At the same time, since there is no fixed molecular or atomic structure within the cavities, the cavities are not prone to permanent damage caused by large electric fields. Hence, this design improves the ability of the print head to withstand the effects of the electrical fields of the electrodes even during long periods of operation.
25

As can be seen in the embodiments shown here, there are solid support structures extending vertically between the neighboring electrode carrier layers 80, 82, 84, e.g. the walls 76 and 78. However, there are advantageously no such solid support structures extending directly between neighboring electrodes. In other words,
30 any straight line extending between two neighboring electrodes extends through at least one of the cavities 71, 71', 71'' or 118. This condition should be met for some or, in particular, all neighboring electrodes of the print head if they carry, in operation, substantially different potentials, in particular differing by a voltage of at least 100 V.

35 This condition may be fulfilled by not placing solid support structures to extend vertically between the electrodes and/or by locally removing sections of the support structures, e.g. at the location of contact lead 38b in Fig. 7.

In yet another embodiment, the field strength may be reduced by designing the electrical tracks to be very narrow at locations where no cavity between the electrodes is provided. In that case, the tracks are advantageously be no more than half as wide as the height of the wall structures 76, 78. If, for example, the wall structures have a height of 5 μm , the tracks should not be wider than 2.5 μm .

Advantageously, the lateral offset between an electrode and the next (i.e. closest) support structure should, for at least one of the two neighboring electrodes, be at least 25% of the vertical distance between the two neighboring electrodes.

Advantageously, at least one of the dielectric layers protecting the electrodes has high relative permittivity ϵ . Thus, the field within it is weak, with the major voltage drops being shifted to the layers of lower permittivity and in particular to the cavities. This allows to even better protect the structure from an electrical breakdown.

In this context, a high relative permittivity ϵ is advantageously at least 5. Suitable materials are e.g. Si_3N_4 (with a relative permittivity ϵ between 9.5 and 10.5) or Al_2O_3 (with ϵ between 9.3 and 11.5).

Advantageously, as shown in Fig. 20, several dielectric layers are provided between the cavity 120 and the electrode 122. (With cavity 120 of Fig. 20 e.g. representing the cavities 118 or 71, 71', 71'' of the examples above and electrode 122 representing one of the electrodes 38, 40, 42 in the examples above, in particular ejection electrode 38.

In the shown embodiment, electrode 122 is enclosed by a first dielectric layer 124a, 124b, which is in turn enclosed by a second dielectric layer 126.

First dielectric layer 124a, 124b is advantageously a polymer layer, e.g. consisting of patterned SU-8 (see manufacturing process below). Such a polymer layer has a low relative permittivity, e.g. between 2.5 and 3.0. It corresponds e.g. to the sublayers 80a, 80b, 82a, 82b, 84a, 84b of the electrode carrier layer 80, 82, 84 described above and may, at least in part, be manufactured using lamination techniques (see below).

Second dielectric layer 126 is an inorganic layer with a higher electric breakdown threshold than first dielectric layer 124a, 124b. It advantageously has a higher relative permittivity than first dielectric layer 124a, 124b, in particular by a factor 2. It may e.g. be of Si_3N_4 or Al_2O_3 for the reasons mentioned above. It has the highest breakdown resistance of all components between two electrodes and typically prevents an electric breakdown.

Placing first dielectric layer 124a, 124b between electrode 122 and second dielectric layer 126 has the advantage that the peak field strengths e.g. at edges of electrode 122 are within the first dielectric layer, thus increasing the ability of second dielectric layer 126 to prevent a breakdown.

5 Hence, in an advantageous embodiment, at least some of the cavities 120 are arranged between different electrodes of the print head or between an electrode of the print head and an ink retainer 66 of the print head.

Advantageously, the different electrodes 38, 40, 42, 122 are separated from the cavity or cavities 120 by one or more solid dielectric layers 124a, 124b, 126.

10 In particular, the one or more solid dielectric layers 124a, 124b, 126 advantageously comprise a polymer layer 124a, 124 and/or an inorganic layer 126. Advantageously, the polymer layer 124a, 124 is arranged between electrode 122 and inorganic layer 126.

15

Operating the Print Head

In operation, i.e. while printing, ink is fed to the print heads by means of the supply ducts 15. This ink is restricted to region 64 between the nozzles 4 and the ink retainers 66.

20 To eject ink drops, the voltage at the desired ejection electrode(s) (in respect to the voltage of the ink) is increased temporarily. For example, a voltage pulse of 400 V may be generated. While not printing, the voltage at the ejection electrodes is maintained at a level where no ink is ejected. Advantageously, it is non-zero, though, e.g. at 200 V.

25 As mentioned above, the electric field at ink retainer 66 is advantageously kept low, e.g. at less than 50%, in particular at less than 10%, of the field strength at the forward end 70 of the nozzle. Since high electric field strengths reduce the surface tension of the ink, this procedure reduces the tendency of the ink to wet the ink retainer and to cross it.

30 The suction ducts 16, if present, are used to retrieve ink from the nozzles. Advantageously, the method for printing comprises the following steps:

- Using the supply ducts 15 in nozzle carrier 6 to individually feed ink to the nozzles and
- 35 - Using suction ducts 16 in nozzle carrier 6 to individually suck ink from the nozzles.

This allows to maintain the reservoir of fresh ink at the nozzles.

In operation, the pressure p_x at the end of the suction duct 16 at a given nozzle is advantageously maintained to keep the ink away from ink retainer 66, such as at the level 64b of Fig. 2. Advantageously, p_x should not be too low to prevent air from being sucked into suction duct 16. A suitable pressure can be calculated
5 from the radial width w of annular duct 62. For $w = 5 \mu\text{m}$ and an ink with the surface tension of water, the Young Laplace equation yields a pressure difference Δp of 144 mbar. For a liquid with the surface tension of alkane, the pressure difference Δp would be 40 mbar. Hence, by keeping the pressure p_x at no more than Δp below ambient pressure, surface 64b can be maintained and no air will be aspirated.

10 If, instead of an annular duct 62, several circular openings of a diameter of e.g. $5 \mu\text{m}$ are used, Δp will be twice as large.

If the difference between the ambient pressure and p_x is less than Δp , the level of liquid will rise, e.g. to line 64a of Fig. 2. There, the curvature is much lower than at line 64b. If we assume, in a simplified example, the curvature is ten
15 times lower, the corresponding pressure difference is 14 mbar (for water). Hence, by e.g. maintaining pressure p_x at 50 mbar below atmosphere, ink can be prevented from reaching a level as high as line 64a.

On the other hand, the pressure p_y at the end of supply duct 15 at a given nozzle can be adjusted to maintain a desired ink flow through the nozzle. Also,
20 and as mentioned above, the ink flow through the exit ducts 56 and 60 can be adjusted by choosing suitable diameters in these ducts.

In yet another embodiment, the pressure difference (below ambient pressure) in the end sections 16a of the suction ducts 16 can be chosen to be larger than Δp at the lower level 64b. Hence, air will be aspirated into the suction ducts 16.

25 If, in that case, the ink returning through the suction ducts 16 is to be recycled, a separation device may be used to separate ink and air before the ink is fed to recirculation pump 18.

Manufacturing

30 The present print head can be manufactured using techniques as they are e.g. known from semiconductor manufacturing and packaging, e.g. as described in WO 2013/000558, WO 2016/120381, and WO 2016/169956.

Advantageously, at least some of the layers of the print head are polymer layers, in particular the intermediate layers 114 of the multilayer structures
35 of the type of Figs. 18, 19 used therein.

Manufacturing such a multilayer structure comprises, advantageously, the following steps:

1. Providing bottom layer 110. This may e.g. be the top layer formed by a previous manufacturing step.

2. Applying a material layer on top of bottom layer 110. This material layer will form intermediate layer 114.

5 3. Applying top layer 112 above the material layer.

The material layers deposited in steps 2 and 3 may be applied using various techniques, such as lamination, spin coating, sputtering, or vapor deposition.

Lamination is particularly advantageous, in particular for applying the top layer 112. In lamination, the layer is applied as a sheet material and connected
10 to the underlying structure e.g. using heat and pressure. This allows to easily span the cavities and/or to create overhanging structures.

The material layer of step 2 is advantageously a photoresist, such as SU-8, which allows to structure it easily. In this case, step 2 comprises at least the following sub-steps:

15 2a: Illuminating the material layer with collimated light through a mask, thereby defining illuminated and non-illuminated regions in the material layer.

2b: Selectively removing the illuminated or the non-illuminated regions from the material layer, depending on if a positive or negative photoresist is used.

20 Alternatively, top layer 112 may also be formed from a solid material, e.g. a glass wafer, that is bonded to the intermediate layer 114, e.g. by adhesive bonding, fusion bonding, eutectic bonding, etc.

Inorganic dielectric layer 126 (Fig. 20) can e.g. be manufactured by depositing it onto the polymer dielectric layers 124a, 124b an atomic layer deposition
25 process.

Notes

In most of the embodiments shown so far, each nozzle is surrounded by an ink retainer, which defines a restricted area where the ink can flow
30 from the nozzle.

In the examples, each nozzle is surrounded by its own ink retainer. Alternatively, several nozzles may be surrounded by a common ink retainer, i.e. one ink retainer may surround several nozzles.

Alternatively or in addition thereto, each support element of support structure 8 may be surrounded by an ink retainer, which defines an ink-free area
35 around the support element, preventing the ink to reach the support element. This

may be particularly advantageous if the support elements are forming individual, isolated pillars.

As can be seen in the embodiments shown above, the guard electrodes 42 are advantageously close to the axis of the nozzle. This is illustrated, by way of example, in Fig. 12.

Here, central axis 100 of nozzle 4, as it extends along ejection direction X, is shown in a dashed line. x_1 is the distance between guard electrode 42 and nozzle axis 100. x_2 is the distance between ink retainer 66 and nozzle axis 100. x_3 is the distance between closest support element 78 and nozzle axis 2, with the support element 78 being the one adjacent to nozzle carrier 6.

The following relations are advantageous:

$x_1 < x_2$, in particular $x_1 < 0.8 \cdot x_2$: By placing guard electrode 42 closer to nozzle axis 100 than ink retainer 66, a better shielding of ink retainer 66 is achieved.

$x_1 < x_3$, in particular $x_1 < 0.8 \cdot x_3$, in particular $x_1 < 0.5 \cdot x_3$: Again, by placing the closest support element 78 further away from axis 100 than guard electrode 42, the support elements are shielded as well.

In addition or alternatively thereto, the difference $x_2 - x_1$ is advantageously at least 50% of the vertical distance d' between guard electrode 42 and ink retainer 66.

In particular, x_3 should be larger than x_2 by at least $1 \mu\text{m}$, in particular by at least $5 \mu\text{m}$.

Hence, the following relations are advantageous, either alone or in any combination:

- The distance x_1 between guard electrode 42 and nozzle axis 100 is smaller than the distance x_2 between ink retainer 66 and nozzle axis 100.

- The distance x_1 between guard electrode 42 and nozzle axis 100 is smaller than the distance x_3 between axis 100 and the support element 78 adjacent to nozzle carrier 6 that is closest to nozzle axis 100.

- The difference $x_2 - x_1$ (between the distance x_1 between guard electrode 42 and nozzle axis 100 and the distance x_2 between ink retainer 66 and nozzle axis 100) is at least 50% of the vertical distance between guard electrode 42 and ink retainer 66.

- The distance x_3 (between axis 100 and the support element 78 adjacent to nozzle carrier 6) is larger than the distance x_2 between ink retainer 66 and nozzle axis 100 by at least $1 \mu\text{m}$, in particular by at least $5 \mu\text{m}$.

- The difference $x2 - x1$ (between the distance $x1$ between guard electrode 42 and nozzle axis 100 and the distance $x2$ between ink retainer 66 and nozzle axis 100) is advantageously at least 50% of the vertical distance between guard electrode 42 and ink retainer 66.

5 As mentioned, the print head may also comprise gas ducts to feed gas to the region between the print head and the target and/or to retrieve gas from said region. These gas duct feeds may also comprise horizontal sections, such as interconnect sections, e.g. in front layer 10 and/or backing layer 12 and/or interposer layer 32, similar to the ink ducts shown in Figs. 13 and 15.

10 In the embodiments described so far, three electrodes at three different vertical levels have been mentioned: the ejection electrodes, the guard electrodes, and the shielding electrodes. It must be noted, though, that there may also be other electrodes, such as:

15 - Electrodes may be provided in nozzle carrier 6, e.g. at the supply ducts 15 and/or suction ducts 16, and/or at the nozzle and/or at the ink retainers for defining the potential of the ink. Such electrodes allow e.g. to keep the ink at a similar or the same potential as the guard electrodes 42. Advantageously, such electrodes are of platinum and/or gold.

20 - Further electrodes (e.g. between ejection electrode 38 and shielding electrode 40 of Fig. 2) may be provided if differently sized nozzles are present on the print head. This is particularly useful for nozzles where the distance between the ejection electrode and the nozzle is considerably smaller than the distance between the shielding electrode and the ejection electrode.

25 While there are shown and described presently preferred embodiments of the invention, it is to be distinctly understood that the invention is not limited thereto but may be otherwise variously embodied and practiced within the scope of the following claims.

Claims

1. An electrohydrodynamic print head comprising
5 a nozzle carrier (6),
a plurality of nozzles (4) arranged on said nozzle carrier (6),
a plurality of ejection electrodes (38) associated with said nozzles
(4) and located on a front side of said nozzles (4),
wherein said print head comprises at least one multilayer structure
10 (109) with a bottom layer (110), a top layer (112), and at least one intermediate layer
(114) between said bottom layer (110) and said top layer (112), wherein said intermediate layer(s) (114) form(s) walls (116) extending between the bottom layer (110) and
the top layer (112),
and wherein a plurality of cavities (118, 120) are located in the in-
15 termediate layer (114) between the bottom layer (110) and said top layer (112).
2. The print head of claim 1 wherein at least part of said cavities
(118), in particular a majority of said cavities (118), are closed cavities.
- 20 3. The print head of any of the preceding claims wherein at least
part of said cavities (118) form a repetitive, regular pattern.
4. The print head of any of the preceding claims wherein said walls
(116) form a honeycomb structure between the bottom layer (110) and the top layer
25 (112).
5. The print head of any of the preceding claims wherein said walls
(116) have a thickness (m) of less than 25% of a minimum diameter (M) of the cavi-
ties (118).
30
6. The print head of any of the preceding claims wherein a mini-
mum diameter (M) of the cavities (118) is larger than a thickness (t) of the intermedi-
ate layer (114).
- 35 7. The print head of any of the preceding claims wherein said walls
(116) extend perpendicularly to the bottom layer (110) and the top layer (112).

8. The print head of any of the preceding claims wherein at least some of said cavities (71, 71', 71'', 120) communicate with and are adjacent to exit passages (5) located at said nozzles (4).

5 9. The print head of any of the preceding claims wherein at least some of said cavities (71) are arranged between different electrodes (38, 40, 42, 122) of said print head,

and in particular wherein any straight line extending between two neighboring electrodes (38, 40, 42, 122) extends through at least one of the cavities
10 (71, 71', 71'').

10. The print head of any of the preceding claims wherein at least some of said cavities (71', 71'') are arranged between an electrode (38, 42, 122) of the print head and an ink retainer (66) of the print head.

15 11. The print head of any of the claims 9 or 10 wherein said different electrodes (38, 40, 42, 122) are separated from the cavity or cavities (118, 120) by one or more solid dielectric layers (124a, 124b, 126).

20 12. The print head of any of the claims 10 or 11 wherein said electrodes (38, 40, 42, 122) are mounted to the bottom layer (110) and/or the top layer (112) of the multilayer structure (109).

25 13. The print head of claim 12 wherein the electrodes (38, 40, 42, 122) are embedded into the bottom layer (110) and/or the top layer (112) of the multilayer structure (109), with the bottom layer (110) and/or top layer (112) forming dielectric solid layers covering the electrodes (38, 40, 42, 122) from the bottom and top sides.

30 14. The print head of any of the claims 11 to 13 wherein said one or more solid dielectric layers (124a, 124b, 126) comprise a polymer layer (124a, 124b) and/or an inorganic layer (126), and in particular wherein said polymer layer (124a, 124) is arranged between said electrode (122) and said inorganic layer (126).

35 15. The print head of any of the claims 10 to 14 further comprising guard electrodes (42) arranged at a level behind the ejection electrodes (38), wherein

at least some of the cavities (71') are arranged between at least one of said ejection electrodes (38) and at least one of said guard electrodes (42).

16. The print head of any of the claims 10 to 15 further comprising
5 at least one shielding electrode (40) arranged at a level in front of the ejection electrodes (38), wherein at least some of the cavities (71'') are arranged between at least one of said ejection electrodes (38) and said shielding electrode (42).

17. The print head of any of the preceding claims wherein the nozzle carrier (6) comprises at least the intermediate layer (114) of the multilayer structure (109).

18. The print head of any of the preceding claims, wherein the nozzle carrier (6) comprises:
15 - a front layer (10), wherein said nozzles (4) are mounted to a front side (36) of the front layer (10), and
- a backing layer (12) located at a back side of the front layer (10),
- electrical vias (14) connected to the ejection electrodes (38) and extending through the front layer (10) and the backing layer (12), and
20 - ink feed ducts (15, 16) arranged in the front layer (10),
wherein the front layer (10) comprises at least the intermediate layer (114),
and in particular wherein there are closed cavities (118) not communicating with the ink ducts (15, 16).

19. The print head of any of the preceding claims further comprising a support structure (8) supporting said ejection electrodes (38) on said nozzle carrier (6), wherein said support structure (8) comprises a plurality of support elements (76, 78) arranged between said nozzles (4),
25 and wherein said support structure (8) comprises at least the intermediate layer (114) of the multilayer structure (109).

20. The print head of claim 19 further comprising a plurality of ink retainers (66) arranged between said nozzles (4) and said support elements (76, 78),
35 wherein, along an ejection direction (X) of the print head, the front surfaces (68) of the ink retainers (66) are located at a level behind the front ends (70) of the nozzles (4).

21. The print head of any of the preceding claims wherein a thickness (t) of said intermediate layer (114) is at least 1 μm , in particular at least 10 μm .

5 22. The print head of any of the preceding claims wherein said intermediate layer (114) is a polymer layer.

23. The print head of any of the preceding claims comprising at least one material layer of a material different from the intermediate layer (114), in particular a semiconductor or glass layer.
10

24. A method for manufacturing the print head of any of the preceding claims comprising the step of
applying a material layer on said bottom layer (110),
15 removing part of said material layer for forming said cavities (118),
applying the top layer (112) above the material layer.

25. The method of claim 24, wherein said material layer is a photoresist, in particular SU-8, and said method comprises the steps of
20 illuminating the material layer with collimated light through a mask,
thereby defining illuminated and non-illuminated regions in said material layer, and
selectively removing the illuminated or the non-illuminated regions from the material layer.

26. The method of any of the claims 24 or 25 comprising the step of
25 applying the top layer (112) above the material layer using lamination.