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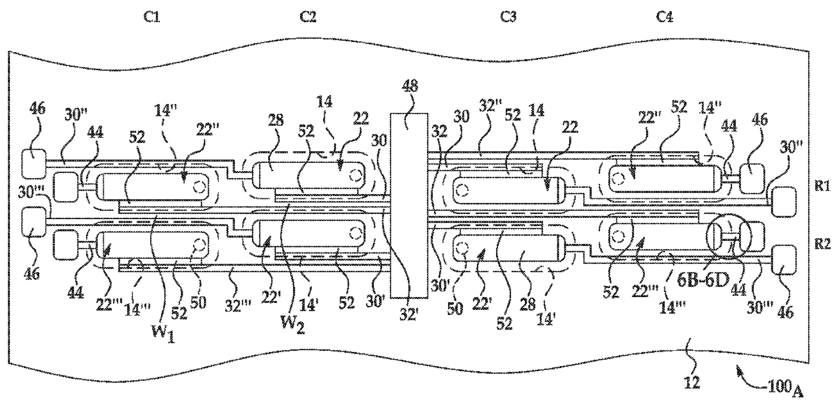

FIG. 6A

(57) Abstract: A printhead architecture includes a die having a chamber formed therein. The chamber is at least partially defined by opposed walls. An actuator is positioned over the chamber, and includes a first electrode, a piezoceramic layer in contact with the first electrode, and a second electrode in contact with the piezoceramic layer and discrete from the first electrode. A membrane, which is to be activated by the actuator, overlies the chamber and walls. A first trace, positioned adjacent to but discrete from the actuator, overlaps a portion of the chamber and a portion of one of the opposed walls. A second trace, positioned adjacent to but discrete from the actuator, overlaps another portion of the chamber and a portion of another one of the opposed walls. Each of the first and second traces has a respective width and thickness sufficient to provide additional stiffness to the membrane.

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PRINTHEAD ARCHITECTURES

BACKGROUND

[0001] Piezoelectric inkjet printing utilizes an actuator and an applied voltage that causes the actuator to change shape. When the voltage is applied, one or more components in direct or indirect contact with the actuator become deformed, which causes ink to eject through a nozzle. The ejection of the ink through the nozzle generates tiny ink droplets that are dispensed onto a printing medium.

BRIEF DESCRIPTION OF THE DRAWINGS

[0002] Features and advantages of examples of the present disclosure will become apparent by reference to the following detailed description and drawings, in which like reference numerals correspond to similar, though perhaps not identical, components. For the sake of brevity, reference numerals or features having a previously described function may or may not be described in connection with other drawings in which they appear.

[0003] Fig. 1 is a schematic, cross-sectional view of a portion of the fluidic and electro-mechanical architecture of one example of a printhead disclosed herein;

[0004] Fig. 2 is a schematic, cross-sectional view of a portion of the fluidic and electro-mechanical architecture of another example of the printhead disclosed herein;

[0005] Fig. 3 is a schematic, cross-sectional view of a portion of the fluidic and electro-mechanical architecture of still another example of the printhead disclosed herein;

[0006] Fig. 4 is a schematic, cross-sectional view of a portion of the fluidic and electro-mechanical architecture of yet another example of the printhead disclosed herein;

[0007] Fig. 5 is a schematic, cross-sectional view of a portion of the fluidic and electro-mechanical architecture of a further example of the printhead disclosed herein;

[0008] Fig. 6A is a cut-away plan view of a portion of one example of the printhead disclosed herein;

[0009] Figs. 6B through 6D are cross-sectional views illustrating different example connections between a trace and a top electrode;

[0010] Fig. 7 is a cut-away plan view of a portion of another example of the printhead disclosed herein;

[0011] Fig. 8 is a cut-away plan view of a portion of still another example of the printhead disclosed herein; and

[0012] Fig. 9 is a plan view of one actuator and associated components of an example of the printhead disclosed herein.

DETAILED DESCRIPTION

[0013] The present disclosure relates generally to printhead architectures. More particularly, the present disclosure relates to the mechanical design of actuated components found in piezoelectric inkjet printheads. In piezoelectric printing, the flux of the ejected fluid is proportional to the firing rate. Flux is the product of drop volume times drop ejection rate. Many printheads with thin film actuators have a single pulse drop volume ranging from about 1 pL to about 4 pL. Ejection rates are often in the range of 50,000 drops/sec to 150,000 drops/sec.

[0014] It has been found that increasing the natural or Helmholtz frequency of the fluidic architecture shortens the time for pressure oscillations, which in turn allows for more rapid damping. Rapid damping may be desirable in applications requiring high flux (i.e., flux greater than 4 pL times 100,000 drops/sec, or 400,000 pL•drops/sec). Examples of the present disclosure include a trace and/or a stiffening member positioned over a portion of a printhead chamber. These trace(s) and/or stiffening member(s) are configured to increase the stiffness of the printhead membrane and actuator, which in turn provides quicker damping, even for printing applications at high print rates. Print rate or ejection rate is the number of drops per second ejected. For single pulse drops, a high print rate may be 100,000 drops/sec or higher. The use of trace(s) and/or stiffening member(s) allows the stiffness to be adjusted without making changes to the membrane and/or the actuator (e.g., without adjusting the width and/or thickness of the membrane and/or the actuator). Furthermore, in some examples, the chambers occupy over 90% of the footprint of the printhead die. The inclusion of the trace(s) and/or stiffening members as disclosed herein effectively utilizes the real estate of the printhead die, which enables a printhead with a high density of nozzles (e.g., 1200 dots per inch) to be generated.

[0015] Referring now to Figs. 1 and 2, cross-sectional views of two examples of a portion of the fluidic and electro-mechanical architecture 10_A and 10_B of respective printheads are depicted. Each of the architectures 10_A and 10_B includes a die 12 having a chamber 14 formed therein. In each of these figures, one of the chambers 14 is labeled 14’ and another of the chambers 14 is labeled 14” in order to facilitate discussion and understanding of the components. It is to be understood that multiple chambers 14, 14’, 14” may be formed in a single die 12 in aligned columns and aligned or offset rows. The cross-sectional views shown in Figs. 1 and 2 may be taken, for example, along one column of chambers 14, 14’, 14” formed in a single die 12.

[0016] It is to be understood that in these and other figures (e.g., Figs. 3-5), a portion of the chambers 14, 14’, 14” is shown, and that a complete chamber 14, 14’, 14” includes an additional floor or side to enclose a fluid within the chamber 14, 14’, 14” so that pressure can be generated when the membrane (reference numeral 16) moves into the chamber 14, 14’, 14”.

[0017] Examples of suitable die materials include silicon, glass, and metal oxides. However, it is to be understood that any die material may be selected that is inert to the fluid to be contained within the chambers 14, 14', 14'', that may be anisotropically etched, and that is compatible with adjacent films, materials, etc. The die 12 may have any desirable dimensions, depending, at least in part, upon the application in which the printhead is to be used. In one example for a piezoelectric printhead, the die dimensions may range from about 5 mm x 25 mm to about 10 mm x 30 mm. The die dimensions may be significantly smaller for certain applications, such as picofluidic systems used for biological and/or chemical dispensing.

[0018] The die 12 also has a membrane 16 attached thereto. In an example, the membrane 16 may be created by deposition of a thin film material onto the surface 15 of the die 12. In another example, the membrane 16 may be created by oxidizing the surface 15 of the die 12 to a desired depth. In an example, the membrane 16 covers one entire surface (e.g., surface 15) of the die 12, such that when the chamber(s) 14, 14' is/are formed in the die 12, the membrane 16 may form a wall of the chamber(s) 14, 14', 14''. In the orientation shown in Figs. 1 and 2, the membrane 16 forms a top wall of the chambers 14, 14', 14''. The membrane 16 may be any suitable flexible material that is capable of transporting vibrations of an actuator (see reference numeral 22) in order to generate transient pressure in fluid (e.g., ink) that is present in a chamber 14 that corresponds with the actuator 22. Some examples of suitable flexible materials for the membrane 16 include glass, silicon, metals, dielectrics, metal oxides, composite materials, or multiple layers of these material(s). Specific examples of suitable metals include tantalum, titanium, molybdenum, niobium, and tungsten. Specific examples of dielectrics include silicon dioxide, silicon nitride, aluminum nitride, titanium nitride, and silicon carbide. Specific examples of metal oxides include aluminum oxide, hafnium oxide, tantalum oxide, and zirconium oxide.

[0019] In an example, the membrane 16 has a thickness ranging from about 1 μm to about 5 μm. In another example, the membrane has a thickness ranging from about 2 μm to about 3 μm, an example of which includes about 2.4 μm. In an example, the membrane 16 and the piezoceramic actuator 22 have approximately the same thicknesses. It is to be understood that the thickness of the membrane 16 may be constrained by the width of the chamber 14, 14', 14". In an example, the widest chambers 14, 14', 14" may be 200 μm, and the corresponding membrane 16 may have a thickness of about 5 μm. In another example, the narrowest chambers 14, 14', 14" may be 45 μm, and the corresponding membrane 16 may have a thickness of about 1 μm.

[0020] The chamber(s) 14, 14', 14" may be formed by etching away portions of the die 12. In an example, the die 12 is etched away from a surface (e.g., surface 17) until the membrane 16 secured to the surface 15 of the die 12 is reached. Any suitable etchant that is selective toward the die 12 material and that will not deleteriously affect the membrane 16 may be used. In an example, the chambers 14, 14', 14" are formed by anisotropically removing silicon by chemical or plasma etching from the side 17 opposite to the membrane layers 16. In this example, the silicon is fully removed in the chamber region so that the bottom of the membrane 26 is exposed to the chamber 14, 14', 14". In other examples, a mask may be used to etch the chamber(s) 14, 14', 14" in desirable position(s). When the chamber(s) 14, 14', 14" is/are etched away, the remaining portions of the die 12 form walls W_1, W_2, W_3, etc. As shown in Figs. 1 and 2, the opposed exterior surfaces of two adjacent walls W_1 and W_2 or W_2 and W_3 form opposed interior surfaces 18, 20, 18', 20', 18", 20" of a corresponding chamber 14, 14', 14". In other words, each chamber 14, 14', 14" is at least partially defined by opposed walls (e.g., W_1 and W_2 or W_2 and W_3). While not shown in Figs. 1 and 2, it is to be understood that the entire perimeter of each chamber 14, 14', 14" is defined by walls of the die 12.

[0021] End(s) (not shown) of each chamber 14, 14', 14" may have openings which act as fluid (e.g., ink) inlets. Reservoirs or other fluid supply systems may be selectively fluidly connected to the openings to supply fluid to the chambers 14, 14', 14".

[0022] The chamber(s) 14, 14', 14" may have any desirable geometry and any desirable dimensions. As examples, suitable chamber geometries include a rectangular geometry (with sharp or rounded corners), a circular geometry, an oval geometry, etc. In an example, the thickness of the chamber(s) 14, 14', 14" corresponds with a thickness of the die 12. The length, width, or diameter of the chamber(s) 14, 14', 14" may be any desirable dimensions, which depend, at least in part on the dimensions of the die 12 and the number of chambers 14, 14', 14" to be formed therein, the number of nozzles that are to be in fluid communication with a single chamber 14, 14', 14" etc. In an example, the width of a rectangular chamber ranges from about 50 μm to about 70 μm and the length of a rectangular chamber ranges from about 0.1 mm to about 5 mm. In another example, the length of the chambers 14, 14', 14" ranges from about 0.75 mm to about 2 mm. Longer chambers 14, 14', 14" enable greater volume displacement for larger drops or lower drive voltages. Longer chambers 14, 14', 14" also have lower natural frequencies and consume more space than shorter chambers 14, 14', 14".

[0023] While not shown in Figs. 1 and 2, it is to be understood that a nozzle plate may be attached to the surface 17 of the die 12 once the chamber(s) 14, 14', 14" is/are formed therein. The nozzle plate may be formed of silicon, metal, ceramic, or polyimide and may include any number of nozzles therein. The array of nozzles is formed in the nozzle plate so that a desirable number of the nozzles are in fluid communication with a respective chamber 14, 14', 14". In an example, a single nozzle is in fluid communication with a single chamber 14, 14', 14", while the entire nozzle plate includes from about 300 nozzles to about 2400 nozzles. The total number of nozzles in a single nozzle plate may depend, at least in part, on the length, density, and number of columns in the printhead. The nozzle plate functions as a wall of the chamber(s) 14, 14', 14", and thus simultaneously seals the chamber(s) 14, 14', 14" while also allowing ink to flow from the printhead via the nozzles when the actuator 22, 22', 22" associated with the chamber 14, 14', 14" is activated.

[0024] The nozzle plate has a chamber side and a fluid exit side. Each nozzle may be tapered on the chamber side with the angle between the nozzle wall and a chamber side surface ranging from about 5° to about 35° from perpendicular. On the fluid exit side of the nozzle plate, the nozzle wall may be perpendicular to a fluid exit side surface.

[0025] In an example in which there are 300 nozzles per inch, center to center spacing of the chambers 14, 14', 14" may be about 84 μm (e.g., 84.6 μm). In this example, the chamber 14, 14', 14" width may be about 70 μm and the wall W_1, W_2, W_3 width may be about 14 μm.

[0026] As shown in Figs. 1 and 2, respective actuators 22, 22', 22" are positioned over respective chambers 14, 14', 14". In each of these figures, the actuator 22 that overlies the chamber 14' is labeled 22' and the actuator 22 that overlies the chamber 14" is labeled 22" in order to facilitate the discussion of the components. It is to be understood that a single actuator 22, 22', 22' is associated with the single chamber 14, 14', 14" that is beneath the single actuator 22, 22', 22". Each actuator 22, 22', 22" is capable of activating the portion of the membrane 16 that lies between the actuator 22, 22', 22" and the respective chamber 14, 14', 14" to dispense fluid from the chamber 14, 14', 14" via the nozzles. When the membrane 16 is activated, it deforms and bends in response to the change in dimensions of the activated actuator 22, 22', 22".

[0027] In general, the actuator(s) 22, 22', 22" include a first electrode 24 or 24', a piezoceramic layer 26 positioned in contact with the first electrode 24 or 24', and a second electrode 28 positioned in contact with the piezoceramic layer 26 and discrete from the first electrode 24 or 24'. The first electrode 24 or 24' and the second electrode 28 are electrically isolated from one another via the piezoceramic layer 26. The positioning of the first and second electrodes 24 or 24' and 28 is such that a voltage is capable of existing between the electrodes 24 or 24' and 28 so as to activate (i.e., change the dimensions of) the piezoceramic layer 26. One of the electrodes 24 or 24' or 28 may be at ground potential or neither of the electrodes 24 or 24' and 28 may be at ground potential. Furthermore, in some examples, all of the first electrodes 24 or 24' or all of the second electrodes 28 may be common (i.e., connected, e.g., by a bus) and at the same electrical potential.

[0028] Suitable materials for the first electrode 24 or 24' include platinum, or a layered structure of platinum and titanium dioxide (Pt/TiO_2), or a layered structure of platinum and titanium (Pt/Ti). In an example, the first electrode 24 or 24' includes a first layer of titanium dioxide or titanium having a thickness ranging from about 5 nm to about 50 nm (e.g., about 20 nm) and a second, outer layer of platinum having a thickness ranging from about 50 nm to about 300 nm (e.g., about 100 nm or about 250 nm). In another example, the first electrode 24 or 24' is formed of platinum, and is about 100 nm thick. Suitable materials for the second electrode 28 include iridium, platinum, ruthenium, iridium oxide (Ir_2O_3), or a layered structure of iridium and iridium oxide. In an example, the second electrode 28 has a thickness ranging from about 50 nm to about 200 nm (e.g., about 100 nm).

[0029] Suitable materials for the piezoceramic layer 26 include lead zirconium titanate (PZT), lead lanthanum zirconium titanate (PLZT, or La doped PZT), lead niobium zirconium titanate (PNZT, or Nb doped PZT), and PMN-PT ($Pb(Mg,Nb)O_3$-$PbTiO_3$). Lead-free piezoceramic layers may also be used, examples of which include $LiNbO_3$, BCTZ [$Ba(Ti_{0.8}Zr_{0.2})O_3$-$(Ba_{0.7}Ca_{0.3})TiO_3$], tungsten bronze structured ferroelectrics (TBSF), BNT-BT [$(Bi_{0.5}Na_{0.5})TiO_3$-$BaTiO_3$], BT [$BaTiO_3$], AlN, AlN doped with Sc, and ternary compositions in the BKT-BNT-BZT [$(Bi_{0.5}K_{0.5})TiO_3$-$(Bi_{0.5}Na_{0.5})TiO_3$-$Bi(Zn_{0.5}Ti_{0.5})O_3$] system (a specific example of which includes $0.4(Bi_{0.5}K_{0.5})TiO_3$-$0.5(Bi_{0.5}Na_{0.5})TiO_3$-$0.1Bi(Zn_{0.5}Ti_{0.5})O_3$). In an example, the piezoceramic layer 26 has a thickness ranging from about 1 μm to about 5 μm. In another example, the piezoceramic layer 26 has a thickness of 2 μm. In still another example, the thickness of the piezoceramic layer 26 is about 2.3 μm. The piezoceramic layer 26 thickness may be smaller or larger depending, at least in part, upon the application in which the layer 26 will be used.

[0030] As shown in Fig. 1, the first electrode 24 may be a blanket (continuous) electrode that is deposited on the entire surface of the membrane 16. In this example, each actuator 22, 22', 22'' includes part of the blanket electrode as its respective first electrode 24. The blanket first electrode 24 may be deposited using any desirable technique, including, for example, physical vapor deposition (PVD) or evaporation.

[0031] As shown in Fig. 2, the first electrode 24' may alternatively be a discrete electrode that is not continuous across the surface of the membrane 16. By "discrete electrode", it is meant that the first electrode 24' of each actuator 22, 22', 22'' is isolated from the first electrodes 24' of each of the other actuators 22, 22', 22'' in the architecture 10_B. The discrete first electrodes 24' may be deposited using any desirable deposition technique, such as those previously described. To form discrete electrodes 24', an electrode material may be blanketly deposited, and then patterned using standard wet or dry etching. Patterning to form the discrete first electrode 24' may take place prior to or after piezoceramic layer 26 formation, or both the discrete first electrode 24' and the piezoceramic layer 26 may be patterned together.

[0032] As shown in Figs. 1 and 2, the piezoceramic layer 26 is formed on the first electrode 24 or 24'. Respective piezoceramic layers 26 may be formed on the blanket first electrode 24 at areas that overlie respective chambers 14, 14', 14'', or respective piezoceramic layers 26 may be formed on each of the discrete first electrodes 24'. As an example, the piezoceramic layer 26 may be deposited on each of the discrete first electrodes 24'. As another example, both the first electrode material and the piezoceramic material may be deposited as blanket layers. In this example, the piezoceramic material may be patterned through wet or dry etching to form the piezoceramic layer 26, and then the first electrode material may be patterned to fabricate the underlying discrete first electrode 24'. In still another example, the first electrode material, the piezoceramic material, and the second electrode material may be deposited as blanket layers. In this example, the second electrode material may be patterned to fabricate the second electrode 28, the piezoceramic material may be patterned to form the piezoceramic layer 26, and then the first electrode material may be patterned to fabricate the underlying discrete first electrode 24'.

[0033] In an example, a passivation layer 34 is formed to protect the piezoceramic layer(s) 26. In particular, it may be desirable to deposit the passivation layer 34 to cover exposed sides S_1, S_2 of the piezoceramic layer(s) 26. The sides S_1, S_2 shown in Figs. 1 and 2 generally extend along the length of actuator 22, 22', 22" (i.e., along a row of the printhead). However, it is to be understood that exposed ends (which extend along the width of the actuator 22, 22', 22" and along a column of the printhead) may also be covered with the passivation layer 34 (see, e.g., Figs. 6B-6D). Deposition of the passivation layer 26 on the sides S_1, S_2 and ends of the piezoceramic layer(s) 26 alone may be difficult, and thus the passivation layer 34 may also be deposited on other components of the architecture 10_A, 10_B of the printheads, including on a portion of the top, sides, and ends of the second electrode 28.

[0034] In the example shown in Fig. 1, the passivation layer 34 may also be deposited on the exposed portions of the blanket first electrode 24. The passivation layer 34 in this example electrically decouples the blanket first electrode 24 and traces subsequently formed thereon (which are described further hereinbelow). As such, the passivation layer 34 in this example may have a thickness suitable for providing electrical isolation between the electrical components. In an example, the thickness of the passivation layer 34 ranges from about 50 nm to about 300 nm. Pin-hole free passivation layers 34 having a thickness within this thickness range may be formed by atomic layer deposition (ALD). In another example, the passivation layer 34 has a thickness that ranges from about 10 nm to about 150 nm. The thinner passivation layer 34 may be suitable in instances where the piezoceramic layer 26 provides electrical isolation between the electrical components (see, e.g., Fig. 6B). While not shown in Fig. 1, it is to be understood that another dielectric layer may be positioned on the passivation layer 34 in order to ensure electrical isolation of the blanket first electrode 24 and the subsequently formed traces. An example of this other dielectric layer is shown as reference numeral 36 in Fig. 6D.

[0035] In the example shown in Fig. 2, the passivation layer 34 may also be deposited on the exposed portions of the membrane 16. While electrical isolation between the membrane 16 and the subsequently formed traces is not needed because the membrane 16 may be formed of a non-conductive material, deposition of a continuous passivation layer 34 between adjacent actuators 22, 22', 22" may be desirable. This layer 34 provides more uniform surfaces upon which traces may be formed. Additionally, damage to the membrane 16 that may otherwise result from etching away the passivation layer 34 from the membrane 16 does not occur. In this example, the thickness of the passivation layer 34 ranges from about 50 nm to about 300 nm.

[0036] It is to be understood that the passivation layer 34 shown in the examples shown in Figs. 1 and 2 does not contribute significantly to the stiffness of the underlying membrane 16. This is due, in part, to the thickness of the passivation layer 34.

[0037] Examples of materials that are suitable for the passivation layer 34 include dielectric materials, such as SiO_2, Al_2O_3, ZrO_2, HfO_2, TiO_2, or the like. In an example, the silicon dioxide passivation layer is prepared by chemical vapor deposition (CVD) or plasma enhanced CVD (PECVD) or some other form of CVD using tetraethyl orthosilicate (TEOS) as an initial reagent. Other suitable deposition techniques for forming the passivation layer 34 include ALD, RF sputtering, sol-gel deposition, or using any technique suitable for forming the piezoceramic layer 26.

[0038] The architectures 10_A and 10_B include traces 30 and 32 that are adjacent to but discrete from the actuator 22. By "discrete from" in this instance, it is meant that each of the traces 30, 32 is positioned a spaced distance from the actuator 22 and are electrically isolated from the actuator 22 unless a connection point is made through or over the passivation layer 34. In each of Figs. 1 and 2, the traces 30 that are adjacent to but discrete from the actuators 22' and 22" are respectively labeled 30' and 30", and the other traces 32 that are adjacent to but discrete from the actuator 22' and 22" are respectively labeled 32' and 32". While not shown in the cross-sectional view, it is to be understood that the traces 30 and 32 may extend length-wise along rows of chambers 14, 14', 14'', and thus may be orthogonal to column(s) of chambers 14, 14', 14''.

[0039] While two traces 30, 32 are shown in Figs. 1 and 2, it is to be understood that additional traces 30, 32 may be positioned between two adjacent actuators 22, 22', 22''. For example, three or more traces 30, 32 may be present between two adjacent actuators 22, 22', 22'' when traces 30, 32 initiate from an edge of the die 12 and/or when multiple columns of chambers 14, 14', 14'' are included.

[0040] In general, the traces 30, 32, 30', 32', 30'', 32'' in the examples shown in Figs. 1 and 2 are positioned to overlap part of a chamber 14, 14', 14'' and part of a wall W_1, W_2, W_3 that defines that chamber 14, 14', 14''. More particularly, in these examples, the trace 30' overlaps a portion of the chamber 14' and the wall W_1, the trace 32' overlaps another portion of the chamber 14' and the wall W_2, the trace 30'' overlaps a portion of the chamber 14'' and the wall W_2, and the trace 32'' overlaps another portion of the chamber 14'' and the wall W_3. The percentage that any trace 30, 30', 30'', 32, 32', 32'' overlaps any chamber 14, 14', 14'' depends, at least in part, on the dimensions of the actuator 22, 22', 22'' associated with that chamber 14, 14', 14'' where the major bending is taking place during activation. In an example, the portion of any chamber 14, 14', 14'' that has a trace 30, 32, or 30', 32', or 30'', 32'' overlapping therewith ranges from about 3% to about 5% of the chamber 14, 14', 14'' width.

[0041] In the following example, all widths that are referred to are the cross-sectional widths that are seen in Figs. 1 and 2. It is to be understood that the lengths extend into or out of the plane of the paper on which the figures are illustrated. In this example, the chamber 14, 14', 14'' has a width of about 60 μm, the actuator 22, 22', 22'' has a width ranging from about 40 μm to about 45 μm, and each trace 30, 32, 30', 32', 30'', 32'' overlaps the respective chamber 14, 14', 14'' width by an amount ranging from about 2 μm to about 5 μm (or from about 3% to about 8% of the width of the chamber 14, 14', 14'').

[0042] It is to be understood that if a wall W_1, W_2, W_3 is curved or has some other non-straight surface, the interior surfaces 18, 20, 18', 20', 18'', 20'' of the chambers 14, 14', 14'' will also be curved or non-straight. In these instances, it is to be understood that the traces 30, 30', 30'', 32, 32', 32'' will be formed to follow the curved or other non-straight walls W_1, W_2, W_3 and interior surfaces 18, 20, 18', 20', 18'', 20'' so that the traces 30, 30', 30'', 32, 32', 32'' overlap in the desired manner.

[0043] The traces 30, 32, 30', 32', 30'', 32'' may be formed of metal. Some traces 30, 32, 30', 32', 30'', 32'' may include a single layer of a single metal, and other traces 30, 32, 30', 32', 30'', 32'' may include multiple layers of multiple metals. When multiple layers are included in a single trace 30, 32, 30', 32', 30'', 32'', the layer that is in contact with the underlying passivation layer 34 may also function as an adhesion promoting layer. Suitable trace metals include chromium, gold, tantalum, titanium, tungsten, platinum, ruthenium, etc. In an example, a single layer trace may be formed of gold. In other examples, multiple layer traces may be formed of titanium under gold, tantalum under gold, nickel under gold, copper-beryllium under gold, or chromium under gold.

[0044] The width and thickness of the traces 30, 32, 30', 32', 30'', 32'' are selected to contribute to the stiffness of the membrane 16. The width and thickness will depend, at least in part on the modulus of the selected trace material(s). The stiffening effect of the trace 30, 32, 30', 32', 30'', 32'' is roughly represented by equation (1):

$$S = A \times E \times w \times t^3 \qquad (1)$$

where S is the stiffness of the trace, A is a constant of proportionality, E is the elastic modulus of the trace, w is the width of the trace overlying the chamber, and t is the thickness of the trace. In an example, each trace 30, 32, 30', 32', 30'', 32'' has a width of about 8 μm. In an example, the width of the trace 30, 32, 30', 32', 30'', 32'' ranges from about 2 μm to about 15 μm. When the single layer trace 30, 32, 30', 32', 30'', 32'' is utilized, the thickness may range from about 100 nm to about 10 μm. In another example, the thickness of the single layer trace 30, 32, 30’, 32’, 30”, 32” may range from about 500 nm to about 2 μm. When the multiple layer trace 30, 32, 30’, 32’, 30”, 32” is utilized, in some examples the total trace thickness may be up to 10 μm, and in other instances, up to 5 μm, and in still other instances, up to 2 μm. In the two-layer examples, the lower layer may have a thickness ranging from about 10 nm to about 10 μm, while the upper layer may have a thickness ranging from about 10 nm to about 10 μm. A single layer in the two-layer system may have the maximum trace thickness (e.g., 10 μm) because the second layer in the two-layer system may be a very thin layer that serves as an adhesion layer for the subsequently applied layer, a dielectric separator for the subsequently applied layer, a passivation layer for the previously applied layer, or the like. In an example, the traces 30, 32, 30’, 32’, 30”, 32” include a lower layer of chromium, tantalum, or titanium having a thickness of about 500 nm and an upper layer of gold having a thickness of about 100 nm.

[0045] As will be described further herein, it is to be understood that the trace 30, 32, 30’, 32’, 30”, 32” may be electrically connected to one of the first electrode 24 or 24’ or the second electrode 28 of the actuator 22, 22’, 22”. Any desirable electrical connections may be made in the examples of Figs. 1 and 2, as long as any one trace 30, 30’, 30”, 32, 32’, 32” electrically connects to one actuator 22, 22’, 22” and overlaps a portion of a chamber 14, 14’, 14” in the desirable manner. A pair of traces 30, 32, or 30’, 32’, or 30”, 32” may be electrically connected to respective electrodes 24 or 24’ and 28 the same actuator 22, 22’, 22”, or the trace 30, 30’, 30” of a pair may be electrically connected to one electrode 24, 24’, or 28 of one actuator 22, 22’, 22” while the trace 32, 32’, 32” of the pair may be electrically connected to one electrode 24, 24’, or 28 of another actuator 22, 22’, 22” (e.g., in a different column).

[0046] Referring now to Fig. 3, a portion of the fluidic and electro-mechanical architecture 10_C of another example of the printhead is depicted. It is to be understood that any of the components shown in Fig. 3 that are also shown and described in reference to Figs. 1 and 2 may not be described again in reference to Fig. 3. While the actuators 22, 22’, 22” shown in Fig. 3 include the discrete first electrodes 24', it is to be understood that this example may include the blanket first electrode 24 instead.

[0047] Rather than traces 30, 32, 30', 32', 30'', 32'' contributing to the membrane stiffness, this example of the architecture 10_C includes a non-conducting stiffening member 38 positioned adjacent to but discrete from each actuator 22, 22', 22''. By "discrete from" in this instance, it is meant that each of the stiffening members 38 is positioned a spaced distance from the adjacent actuators 22, 22', 22''. While not shown in the cross-sectional view, it is to be understood that the stiffening members 38 may extend length-wise along rows of chambers 14, 14', 14'', and thus may be orthogonal to column(s) of chambers 14, 14', 14''.

[0048] In general, each of the stiffening members 38 in the example shown in Fig. 3 is positioned to overlap part of two adjacent chambers 14, 14', 14'' in a column of chambers and a wall W_1, W_2, W_3 that defines part of each of the two adjacent chambers 14, 14', 14''. More particularly, in this example, the stiffening member 38 overlying wall W_1 overlaps a portion of the chamber 14 (at the left side of the figure) and a portion of the chamber 14', the stiffening member 38 overlying wall W_2 overlaps a portion of the chamber 14' and a portion of the chamber 14'', and the stiffening member 38 overlying wall W_3 overlaps a portion of the chamber 14'' and a portion of the chamber 14 (at the right side of the figure). As depicted, the stiffening member 38 overlaps a portion of the width of the chamber 14, 14', 14''. The percentage that any stiffening member 38 overlaps any chamber 14, 14', 14'' depends, at least in part, on the dimensions of the actuator 22, 22', 22'' associated with that chamber 14, 14', 14'' where the major bending is taking place during activation. In an example, the portion of any chamber 14, 14', 14'' that has a stiffening member 38 overlapping therewith ranges from about 3% to about 8% of the chamber 14, 14', 14'' width.

[0049] It is to be understood that if a wall W_1, W_2, W_3 is curved or has some other non-straight surface, the interior surfaces 18, 20, 18', 20', 18'', 20'' of the chambers 14, 14', 14'' will also be curved or non-straight. In these instances, it is to be understood that the stiffening members 38 will be formed to follow the curved or other non-straight walls W_1, W_2, W_3 and interior surfaces 18, 20, 18', 20', 18'', 20'' so that the stiffening members 38 overlap in the desired manner.

[0050] The stiffening members 38 may be formed of a dielectric material. In examples where the discrete electrodes 24' are utilized (e.g., Fig. 3), suitable dielectric materials for the stiffening members 38 include PZT, ZrO_2, HfO_2, $BaTiO_3$, or any other suitable piezoelectric or non-piezoelectric dielectric material. In examples where the blanket electrode 24 is utilized (e.g., Fig. 4), suitable dielectric materials for the stiffening members 38 include ZrO_2, HfO_2, or any other suitable non-piezoelectric dielectric material.

[0051] The width and thickness of the stiffening members 38 are selected to contribute to the stiffness of the membrane 16. The width and thickness will depend, at least in part on the modulus of the selected stiffening member material(s). The stiffening effect of the stiffening members 38 is roughly represented by equation 1 provided herein, except that S is the stiffness of the stiffening member, A is a constant of proportionality, E is the elastic modulus of the stiffening member, w is the width of the stiffening member overlying the chamber, and t is the thickness of the stiffening member. The width of the stiffness member 38 is greater than the width of the corresponding wall W_1, W_2, W_3 and less than the distance between two adjacent actuators 22, 22', 22''. In an example, each stiffening member 38 has a width of about 34.5 μm. In other examples, the width of each stiffening member 38 is as little as 14 μm or as much as 37 μm. The thickness of the stiffening member 38 may range from about 200 nm to about 10 μm.

[0052] In the example shown in Fig. 3, traces 30, 32, 30', 32', 30'', 32'' are not incorporated between the actuators 22, 22', 22''. In this example, the stiffening members 38 alone provide the desired stiffness. Electrical connections to the various electrodes 24 or 24' and 28 may be made using wire bonds (e.g., which may be connected to the respective second/top electrodes 28) or traces that extend from an edge of the die 12 or from a common bus directly to an end of the respective first/bottom electrodes 24 or 24', and thus are not positioned between adjacent actuators 22, 22', 22".

[0053] Referring now to Fig. 4, a portion of the fluidic and electro-mechanical architecture 10_D of still another example of the printhead is depicted. It is to be understood that any of the components shown in Fig. 4 that are also shown and described in reference to Figs. 1, 2 and/or 3 may not be described again in reference to Fig. 4. While the actuators 22, 22', 22" shown in Fig. 4 include the blanket first electrode 24, it is to be understood that this example may include the discrete first electrodes 24' instead.

[0054] In this example, the architecture 10_D includes both the non-conducting stiffening member 38 positioned adjacent to but discrete from each actuator 22, 22', 22", and includes traces 40, 42 formed on each stiffening member 38.

[0055] The stiffening member 38 is the same stiffening member 38 that is described in reference to Fig. 3. In particular, each of the stiffening members 38 shown in Fig. 4 overlaps a portion of two adjacent chambers 14, 14', 14" in a column of chambers 14, 14', 14" and also overlaps a wall W_1, W_2, W_3 that defines part of each of the two adjacent chambers 14, 14', 14". Furthermore, the width and thickness of the stiffening members 38 are selected to contribute to the stiffness of the membrane 16.

[0056] The traces 40, 42 in this example are formed on the stiffening members 38 so that they do not overlap with any portion of any adjacent chamber 14, 14', 14". These traces 40, 42 overlie a respective wall W_1, W_2, W_3, but do not extend beyond the edges of the wall W_1, W_2, W_3. As such, these traces 40, 42 generally do not contribute significantly to the stiffness of the membrane 16.

[0057] Since the traces 40, 42 do not overlap with an adjacent chamber 14, 14', 14", the width of the traces 40, 42 may be more narrow than the width of the traces 30, 32, 30', 32', 30", 32". An example of the width of the traces 40, 42 ranges from about 2 μm to about 15 μm. In another example, the width of the traces 40, 42 ranges from about 2 μm to about 5 μm. The narrow-width traces 40, 42 may have a thickness that is large enough to ensure conductivity (i.e., low voltage drops and power losses). The thickness of the traces 40, 42 may range from about 10 nm to about 10 μm.

[0058] The traces 40, 42 may be formed of any of the materials and by any of the methods previously described for the traces 30, 32, 30', 32', 30'', 32''. Furthermore, each of the traces 40, 42 may be electrically connected to a single electrode 24, 24' or 28 in any suitable manner.

[0059] Referring now to Fig. 5, a portion of the fluidic and electro-mechanical architecture 10_E of still another example of the printhead is depicted. It is to be understood that any of the components shown in Fig. 5 that are also shown and described in reference to Figs. 1, 2, 3 and/or 4 may not be described again in reference to Fig. 5. While the actuators 22, 22', 22'' shown in Fig. 5 include the discrete first electrodes 24', it is to be understood that this example may include the blanket first electrode 24 instead.

[0060] In this example, the architecture 10_E includes the non-conducting stiffening member 38 positioned adjacent to but discrete from each actuator 22, 22', 22'', and also includes traces 30, 32, or 30', 32', or 30'', 32'' formed on the stiffening member 38.

[0061] Each of the stiffening members 38 shown in Fig. 5 overlaps a respective portion of two adjacent chambers 14, 14', 14'' in a column of chambers 14, 14', 14'', and also overlaps the wall W_1, W_2, W_3 that defines part of each of the two adjacent chambers 14, 14', 14''. The traces 30, 32, 30', 32', 30'', 32'' shown in Fig. 5 are positioned on the stiffening members 38 so that each trace 30, 32, 30', 32', 30'', 32'' overlaps part of a chamber 14, 14', 14'' and part of the wall W_1, W_2, W_3 that defines that chamber 14, 14', 14''. The trace 30, 32, 30', 32', 30'', 32'' may have the same percentage of overlap with the chamber 14, 14', 14'' as the stiffening member 38 upon which the trace 30, 32, 30', 32', 30'', 32'' is formed, or the trace 30, 32, 30', 32', 30'', 32'' may have less percentage of overlap with the chamber 14, 14', 14'' than the stiffening member 38 upon which the trace 30, 32, 30', 32', 30'', 32'' is formed.

[0062] In the example of Fig. 5, the stiffening members 38 and the traces 30, 32, 30', 32', 30'', 32'' contribute to the stiffness of the membrane 16 near the walls W_1, W_2, W_3 and the interior surfaces 18, 20 , 18', 20', 18'', 20'' of the chambers 14, 14', 14''. As such, in this example, the width and the thickness of the stiffening members 38 and of the traces 30, 32, 30', 32', 30'', 32'' are selected to achieve the desirable stiffness.

[0063] In an example, the stiffening member 38 is the primary contributor to the increased stiffness. In this example, the traces 30, 32, 30', 32', 30'', 32'' are much thinner than the stiffening member 38. Stiffness will increase monotonically with the thickness and width of the stiffening member 38. Selection of suitable dimensions will depend upon the desired thickness and manufacturing considerations for cost and reliability. The stiffening member 38 being the primary stiffness contributor may be desirable to conserve metal and processing costs. The stiffening member 38 being the primary stiffness contributor may also be desirable, for example, when a single trace 30, 32, 30', 32', 30'', 32'' is formed on the stiffening member 38. In this example, the presence or lack of the trace 30, 32, 30', 32', 30'', 32'' will not lead to a significant different in the overall stiffness that is provided to the membrane 16.

[0064] Figs. 6A and 7-9 illustrate different plan views for the architectures 10_A, 10_B, 10_C, 10_D, 10_E and printheads disclosed herein. These figures illustrate various chamber and actuator configurations, various trace and/or stiffening member configurations, and various electrical connections that can be made.

[0065] Referring now to Fig. 6A, a plan view 100_A of a portion of a printhead is depicted. Architectures 10_A, 10_B, 10_D, and 10_E may be particularly suitable for this plan view 100_A. In this example, the plan view 100_A includes four columns C1, C2, C3, C4 of chambers 14, 14', 14'' and two offset rows R1, R2 of chambers 14, 14', 14''. Also in this plan view 100_A (as well as the plan views shown in Figs. 7 and 8), the first/bottom electrodes 24' are discrete bottom electrodes that are positioned beneath the piezoceramic layer 26, which is positioned beneath the second/top electrode 28. Furthermore, components such as the membrane 16 and the passivation layer 34 are not shown for clarity.

[0066] The plan view 100_A includes a common bus 48 that extends along a center portion of the die 12. Each of the traces 30, 30', 32', 33'', 32''' that operatively connects to a respective first/bottom electrode 24 or 24' is connected to the common bus 48. This enables the first/bottom electrodes 24 or 24' to be common (i.e., connected via the bus 48 and at the same electrical potential). It is to be understood that for a connection to be made between the traces 30, 30', 32', 33'', 32''' and the respective first/bottom electrodes 24 or 24', the passivation layer 24 and/or the piezoceramic layer 26 is etched or otherwise removed in order to create a connection point/area 52 where the traces 30, 30', 32', 33'', 32''' can be connected to the respective first/bottom electrodes 24 or 24'. In this example, the connection point/area 52 is along the sides of the first electrode 24, 24' that extend along the rows R1, R2. This type of connection point/area 52 may be desirable, for example, when the first electrode 24, 24 is so thin that the electrical resistivity is too high for an end connection.

[0067] As illustrated, the traces 30 partially overlap respective chambers 14 on one side (a side that runs parallel with the rows) and are electrically connected to respective first/bottom electrodes 24 or 24' of the actuators 22 that are positioned over these chambers 14. As illustrated to the left of the common bus 48, the chamber 14 does not have a trace overlapping the opposed side of the chamber 14. It is to be understood that a stiffening member 38 and/or a dummy trace may be incorporated at this position if desirable.

[0068] Also as illustrated, traces 30' partially overlap respective chambers 14' on one side (a side that runs parallel with the rows) and are electrically connected to respective first/bottom electrodes 24 or 24' of the actuators 22' that are positioned over these chambers 14'. As illustrated to the right of the common bus 48, the chamber 14' does not have a trace overlapping the opposed side of the chamber 14'. It is to be understood that a stiffening member 38 and/or a dummy trace may be incorporated at this position if desirable for symmetric bending.

[0069] The common traces 32 and 32” extend from the common bus 48 to first electrodes 24 or 24’ of the chambers 14’” and 14” in column C4, respectively. As illustrated, trace 32” does not overlap any chamber 14, 14’ in column C3, but does overlap a portion of chamber 14” in column C4. Trace 32, however, overlaps a portion of each of chamber 14 in column C3 and chamber 14’” in column C4. It is noted that the trace 32 is not electrically connected to the actuator 22 associated with chamber 14 in column C3, but the trace 32 does contribute to the stiffness of the membrane 16 at an area where trace 32 overlaps with the chamber 14 and its adjacent wall W_2.

[0070] The common traces 32’ and 32’” extend from the common bus 48 to first electrodes 24 or 24’ of the chambers 14” and 14’” in column C1, respectively. As illustrated, trace 32’” does not overlap any chamber 14, 14’ in column C2, but does overlap a portion of chamber 14’” in column C1. Trace 32’, however, overlaps a portion of each of chamber 14’ in column C2 and chamber 14” in column C1. It is noted that the trace 32’ is not electrically connected to the actuator 22’ associated with chamber 14’ in column C1, but the trace 32’ does contribute to the stiffness of the membrane 16 at the area where trace 32’ overlaps with the chamber 14’ and its adjacent wall W_2.

[0071] While the common bus 48 is shown extending between columns C2 and C3 along the center of the die 12, it is to be understood that the common bus 48 may also be positioned at or near an edge of the die 12.

[0072] The plan view 100_A also includes bond pads 46, which are operatively and electrically connected to a single trace 30”, 30’” or 44. Each of the traces 30”, 30’” or 44 operatively connects to a respective second/top electrode 28. Examples of such connections are described further in reference to Figs. 6B through 6D.

[0073] As illustrated, some of the traces 44 directly connect from the bond pad 46 to a respective second/top electrode 28 without overlapping with any of the sides of the chambers 14, 14’, 14” that extend along the offset rows R1, R2. In the example shown in Fig. 6A, the traces 44 are electrically connected, respectively, to the second/top electrodes of actuators 22’ and 22’” in columns C1 and C4. These traces 44 may be formed of the same materials and via same methods previously described herein, but they do not contribute to the stiffness of the membrane 16.

[0074] Also as illustrated, traces 30'' partially overlap respective chambers 14'' (in columns C1 and C4) on one side that runs parallel with the general direction of the rows R1, R2, and are electrically connected to respective second/top electrodes 28 of the actuators 22 that are positioned over the chambers 14 in columns C2 and C3. As such, the traces 30'' provide stiffness to chambers 14'' that the traces 30'' are not electrically connected to.

[0075] Similar to traces 30'', the traces 30''' provide stiffness to chambers that the traces 30''' are not electrically connected to. More particularly, traces 30''' partially overlap respective chambers 14''' (in columns C1 and C4) on one side that runs parallel with the general direction of the rows R1, R2, and are electrically connected to respective second/top electrodes 28 of the actuators 22' that are positioned over the chambers 14' in columns C2 and C3.

[0076] As illustrated in the plan view 100_A, the use of the real estate of the die 12 is maximized by incorporating traces 30, 32, 30', 32', 30'', 32'' between the offset rows R1, R2 and in some instances, partially overlapping the chambers 14, 14', 14'', 14'''.

[0077] Nozzles 50 of each of the chambers 14, 14', 14'', 14''' are shown near one end of the chambers 14, 14', 14'', 14'''. Fluid is ejected through these nozzles 50 when the respective actuators 22, 22', 22'', 22''' are activated by the respective electrodes 24 or 24' and 28.

[0078] As mentioned above, Figs. 6B through 6D illustrate various examples of how the trace 44 (and/or 30, 32, 30', 32', 30'', 32'', 40 and/or 42) may be connected to the second/top electrode 28. These figures are cross-sectional views of one of the opposed ends of the actuators 22, 22', 22'', which are located are either end of a single column. It is noted that these cross-sectional views are also cut-away view, and thus components, such as the chamber 14, 14', 14'', bond pad 46, etc., are not shown.

[0079] In Fig. 6B, the end $E_{24'}$ of the discrete first electrode 24’ is covered by the piezoceramic layer 26. The piezoceramic layer 26 extends outward a suitable distance from the end $E_{24'}$ so that isolation of the discrete first electrode 24’ and the trace 44 is achieved. The distance that the piezoceramic layer 26 extends from the end $E_{24'}$ may be equal to the thickness of the piezoceramic layer 26. In an example, the distance is not less than ½ the thickness of the piezoceramic layer 26. In this example, the passivation layer 34 is not present on the opposed ends of the actuator 22, 22’, 22”. As such, the trace 44 is established directly on the membrane 16, along the end E_{26} of the piezoceramic layer 26, and in contact with the second electrode 28.

[0080] In Fig. 6C, the blanket first electrode 24 is covered in part by the piezoceramic layer 26 and by the passivation layer 34. The passivation layer 34 extends along the end E_{26} and onto the second electrode 28. The trace 44 is established directly on the passivation layer 34 and is continued beyond the passivation layer 34 so that it is in contact with the second electrode 28.

[0081] In Fig. 6D, the blanket first electrode 24 is covered in part by the piezoceramic layer 26 and by the passivation layer 34. The additional dielectric layer 36 is also deposited on the passivation layer 34. This additional dielectric layer 36 ensures electrical isolation between the blanket first electrode 24 and the trace 44 for the second electrode 28. The passivation layer 34 and the additional dielectric layer 36 extend along the end E_{26} and into the second electrode 28. The trace 44 is established directly on the additional dielectric layer 36 and is continued beyond the additional dielectric layer 36 and the passivation layer 34 so that it is in contact with the second electrode 28.

[0082] Referring now to Fig. 7, another plan view 100_B is depicted. This simplified view includes two columns C1, C2 and one offset row R1. In this example, the connections from the traces 30, 30’, 44, 44’ to the respective electrodes 24, 24’ or 28 are end connections.

[0083] In this example, each of the traces 30 and 44 is respectively operatively connected to a first/bottom electrode 24 or 24’ of the actuator 22’ and 22. It is to be understood that for an end connection to be made between the traces 30, 44 and the respective first/bottom electrodes 24 or 24', the passivation layer 24 and/or the piezoceramic layer 26 is etched or otherwise removed in order to create the connection point/area 52 where the traces 30, 44 can be connected to the respective first/bottom electrodes 24 or 24'. In this example, the connection point/area 52 is along the ends of the first electrode 24, 24' that extend along the columns C1, C2 (i.e., along the width of the chambers 14, 14').

[0084] As illustrated, the trace 30 partially overlaps chamber 14 on one side (a side that runs parallel with the row R1) and is electrically connected to the first/bottom electrode 24 or 24' of the actuator 22' in column C2. In particular, the trace 30 partially overlaps wall W_1 and the side/portion of the chamber 14 defined by the wall W_1. It is noted that the trace 30 is not electrically connected to the actuator 22 associated with chamber 14 in column C1, but the trace 30 does contribute to the stiffness of the membrane 16 at an area where trace 30 overlaps with the chamber 14 and its adjacent wall W_1. The trace 44 directly connects to the first/bottom electrode 24 or 24' of the actuator 22 in column C1 without overlapping with any of the sides of the chambers 14, 14', 14'' that extend along the offset row R1. It is to be understood that this trace 44 may be configured to overlap a portion of a chamber 14, 14', 14'' in another column that is not shown.

[0085] In this example, each of the traces 30' and 44' is respectively operatively connected to a second/top electrode 28 of the actuator 22 and 22'. Examples of these end connections are shown and described in reference to Figs. 6B through 6D.

[0086] As illustrated, the trace 30' partially overlaps chamber 14' on one side (a side that runs parallel with the row R1) and is electrically connected to the second/top electrode 28 of the actuator 22 in column C1. In particular, the trace 30' partially overlaps wall W_2 and the side/portion of the chamber 14' defined by the wall W_2. It is noted that the trace 30' is not electrically connected to the actuator 22' associated with chamber 14' in column C2, but the trace 30' does contribute to the stiffness of the membrane 16 at an area where trace 30' overlaps with the chamber 14' and its adjacent wall W_2. The trace 44' directly connects to the second/top electrode 28 of the actuator 22' in column C2 without overlapping with any of the sides of the chambers 14, 14', 14'' that extend along the offset row R1. It is to be understood that this trace 44' may be configured to overlap a portion of a chamber 14, 14', 14'' in another column that is not shown.

[0087] In this plan view 100_B, a stiffening member 38 or a dummy, unconnected trace 32, 32' may be positioned to overlap walls W_1, W_2 and adjacent chambers 14, 14' where connecting traces 30, 30' are not positioned. These stiffening member(s) 38 or dummy, unconnected trace(s) 32, 32' may add stiffness without providing any electrical connections. As shown in Fig. 7, the stiffening member 38 or the dummy, unconnected trace 32, 32' may be positioned to overlap i) the wall W_2 and the side portion of the chamber 14 adjacent to wall W_2 and/or ii) the wall W_1 and the side portion of the chamber 14' adjacent to wall W_1.

[0088] While a common bus 48 and bond pads 46 are not shown in Fig. 7, it is to be understood that the traces 30 and 44 or 30' and 44' may be attached to the common bus 48 while the other traces 30' and 44' or 30 and 44 may be attached to the bond pads 46. As an example, the common bus 48 may extend along the center of the die 12 with the columns of chambers 14, 14', 14'' positioned on either side. Alternatively, two common buses may be included, where traces 30 and 44 are connected to one common bus, and traces 30' and 44' are connected to another common bus.

[0089] Referring now to Fig. 8, still another plan view 100_C is depicted. This example illustrates one column C1 and two aligned rows R1, R2, although a second column is noted. In this example, two actuators 22_A, 22_B overlap the chamber 14 and two actuators $22'_A$, $22'_B$ overlap the chamber 14'. When activated, both actuators 22_A, 22_B or $22'_A$, $22'_B$ work to drive fluid out of the nozzles 50 of the associated chambers 14, 14'.

[0090] While not shown, the plan view 100_C includes a common bus from which the traces 30 and 32' extend. Each of the traces 30 and 32' that extends from the common bus respectively operatively connects to the first/bottom electrodes 24 or

24’ of the actuators 22_A, 22_B and $22'_A$, $22'_B$. This enables the first/bottom electrodes 24 or 24’ to be common (i.e., connected via the bus and at the same electrical potential). It is to be understood that for a connection to be made between the traces 30 and 32’ and the respective first/bottom electrodes 24 or 24’, the passivation layer 24 and/or the piezoceramic layer 26 is etched or otherwise removed in order to create a connection point/area 52 where the traces 30 and 32’ can be connected to the respective first/bottom electrodes 24 or 24’. In this example, the connection point/area 52 is along the sides of the first electrodes 24, 24’ that extend along the rows R1, R2.

[0091] As illustrated, the trace 30 partially overlaps chamber 14 on one side (a side that runs parallel with the rows) and is electrically connected to respective first/bottom electrodes 24 or 24’ of the actuators 22_A, 22_B that are positioned over the chamber 14. Also as illustrated, trace 32’ partially overlaps chambers 14’ on one side (a side that runs parallel with the rows) and is electrically connected to respective first/bottom electrodes 24 or 24’ of the actuators $22'_A$, $22'_B$ that are positioned over the chambers 14’.

[0092] The plan view 100_A also includes bond pads 46, which are operatively and electrically connected to a single trace 30’, 30’’, 32, and 32’’. As illustrated, the trace 32 partially overlaps chamber 14 on one side (a side that runs parallel with the rows) and is electrically connected to the ends of respective second/top electrodes 28 of the actuators 22_A, 22_B that are positioned over the chamber 14. Also as illustrated, trace 30’ partially overlaps chambers 14’ on one side (a side that runs parallel with the rows) and is electrically connected to the ends of respective second/top electrodes 28 of the actuators $22'_A$, $22'_B$ that are positioned over the chambers 14’.

[0093] Traces 30’’ and 32’’ are electrically isolated from adjacent traces (e.g., 32 and 32’ or 30’) and extend between or next to chambers 14, 14’. These traces 30’’ and 32’’ may be configured to electrically connect to an electrode in another column and/or to overlap a wall and chamber in another column.

[0094] As illustrated in the plan view 100_C, the use of the real estate of the die 12 is maximized by incorporating traces 30, 32, 30', 32', 30", 32" between the rows R1, R2 and in some instances, partially overlapping the chambers 14, 14'.

[0095] Fig. 9 depicted still another plan view 100_D for the printheads disclosed herein. In this example, interdigitated electrodes 24" and 28' are utilized. Each electrode 24" and 28' is deposited on or embedded in the piezoceramic layer 26.

[0096] The electrodes 24" and 28' have a number of fingers A, B, C, D extending along the length of the piezoceramic layer 26, and a bar E, F extending along the width of the piezoceramic layer 26 that electrically connects the respective fingers A, B, C, D together. The bars F of the electrode 28' are disposed at opposite ends of the piezoceramic layer 26. The fingers A, B of the electrode 24" are interleaved in relation to the fingers C, D of the electrode 28', and vice-versa. In this sense, the electrode 28' is said to be interdigitated in relation to the electrode 24", and vice-versa. In an example, the fingers A, B, C, D may be equally spaced in relation to one another, to achieve identical electrical field distributions in the regions between the fingers A, B, C, D, ensuring uniform deformation of the piezoceramic layer 26. This may be particularly desirable when the piezoceramic layer 26 does not cover the entire chamber 14, as shown in Fig. 9.

[0097] The electrode 24" is electrically connected to a trace 30, and the electrode 28' is electrically connected to a trace 32. These traces 30, 32 are connected to respective bond pads 46 and are positioned over respective stiffening members 38.

[0098] As illustrated, the trace 30 and its associated stiffening member 38 partially overlaps chamber 14 on the side adjacent to and partially defined by wall W_2. The trace 30 and its associated stiffening member 38 also partially overlap or overlap the wall W_2. The trace 32 and its associated stiffening member 38 partially overlaps chamber 14 on the side adjacent to and partially defined by wall W_1. The trace 32 and its associated stiffening member 38 also partially overlap or completely overlap the wall W_1.

[0099] In this example, application of a voltage between the electrodes 24'', 28' induces an electric field in regions within the piezoceramic layer 26 at least substantially parallel to the plane of the piezoceramic layer 26, which causes the piezoceramic layer 26 to physically deform. This, in turn, causes the underlying membrane 16 to deform, which pressurizes fluid in the associated chamber 14, causing the fluid to eject from the associated nozzle 50.

[0100] In any of the examples disclosed herein, dummy traces may be utilized. As mentioned above, these dummy traces are metal and positioned partially over the wall and an adjacent chamber, but are not electrically connected to any electrode. As an example, it may be desirable that the trace 30, 32, 30', 32', 30'', 32'' contribute to stiffness but not be electrically connected to any electrode 24, 24', or 28 of any actuator 22, 22', 22''.

[0101] To further illustrate the present disclosure, an example is given herein. It is to be understood that this example is provided for illustrative purposes and is not to be construed as limiting the scope of the present disclosure.

EXAMPLE

[0102] Printheads with 60-μm-wide chambers, 24.7 μm wide chamber walls, a 2.3 μm thick membrane, and a 2.3 μm thick PZT piezoceramic layer were compared with and without an 11 μm wide and a 0.6 μm thick trace over the edge of the chamber wall (i.e., 7.35 μm over the wall and 3.65 μm over the adjacent chamber). The 0.6 μm thick trace included a bottom layer of 0.5 μm thick Ta and a top layer of 0.1 μm thick Au.

[0103] Finite element analysis was used to compare volume changes under static pressure and electric fields. In particular, finite element analysis was used to compute membrane displacement due to an applied pressure and an applied electric field for geometries whose only difference was the presence of the trace. The results indicated that when the trace was included, pressure compliance was decreased from 2016 pL/MPa to 1657 pL/MPa, or about 18%. The results also indicated that when the trace was included, electric field compliance was decreased from 144.9 pL/(MV/m) to 123.4 pL/(MV/m), or about 15%. These results indicate that the added trace enhanced the stiffness of the underlying membrane.

[0104] It is to be understood that the ranges provided herein include the stated range and any value or sub-range within the stated range. For example, a range from about 3% to about 8% should be interpreted to include not only the explicitly recited limits of about 3% to about 8%, but also to include individual values, such as 3.7%, 4%, 4.3%, 5%, 7.2%, etc., and sub-ranges, such as from about 3.5% to about 4.5%, from about 4% to about 7%, etc. Furthermore, when “about” is utilized to describe a value, this is meant to encompass minor variations (up to +/- 10%) from the stated value.

[0105] While several examples have been described in detail, it will be apparent to those skilled in the art that the disclosed examples may be modified. Therefore, the foregoing description is to be considered non-limiting.

<u>What is claimed is:</u>

1. A printhead architecture, comprising:

a die having a chamber formed therein, the chamber being at least partially defined by opposed walls;

an actuator positioned over the chamber, the actuator including:

a first electrode;

a piezoceramic layer in contact with the first electrode;

a second electrode in contact with the piezoceramic layer and discrete from the first electrode;

a membrane overlying the chamber and the walls, the membrane to be activated by the actuator;

a first trace positioned adjacent to but discrete from the actuator, the first trace overlapping a portion of the chamber and a portion of one of the opposed walls, the first trace having a width and a thickness sufficient to provide additional stiffness to the membrane; and

a second trace positioned adjacent to but discrete from the actuator, the second trace overlapping an other portion of the chamber and a portion of an other one of the opposed walls, the second trace having a width and a thickness sufficient to provide further additional stiffness to the membrane.

2. The printhead architecture as defined in claim 1 wherein:

the die has a plurality of chambers formed therein such that the chambers are arranged in aligned columns and offset rows, each of the plurality of chambers being at least partially defined by respective opposed walls;

each of the plurality of chambers has a respective actuator associated therewith; and

each of the respective actuators in a single column has positioned adjacent thereto but discrete therefrom respective first and second traces.

3. The printhead architecture as defined in claim 2 wherein any of:

at least one of the respective first and second traces overlaps at least one of the respective opposed walls along a respective one of the offset rows; or

each of the respective first and second traces does not overlap any other of the plurality of chambers.

4. The printhead architecture as defined in claim 1 wherein the first and second electrodes are interdigitated electrodes positioned on the piezoceramic layer.

5. The printhead architecture as defined in claim 1 wherein:

the portion of the chamber that the first trace overlaps is up to about 8% of the chamber width; and

the other portion of the chamber that the second trace overlaps is up to about 8% of the chamber width.

6. The printhead architecture as defined in claim 1 wherein the second electrode is a blanket electrode, and wherein the printhead further comprises a passivation layer positioned between the second electrode and the first trace and between the second electrode and at least a portion of the second trace.

7. The printhead architecture as defined in claim 1 wherein:

the first and second traces are each positioned on the membrane; and

a passivation layer is positioned between the first and second traces and the membrane.

8. A printhead architecture, comprising:

a die having a chamber formed therein, the chamber being at least partially defined by opposed walls;

an actuator positioned over the chamber, the actuator including:

a first electrode;

a piezoceramic layer in contact with the first electrode;

a second electrode in contact with the piezoceramic layer and discrete from the first electrode;

a membrane overlying the chamber and the walls, the membrane to be activated by the actuator;

a first non-conducting stiffening member positioned adjacent to but discrete from the actuator, the first non-conducting stiffening member overlapping a portion of the chamber and one of the opposed walls, and the first non-conducting stiffening member having a width and a thickness sufficient to provide additional stiffness to the membrane; and

a second non-conducting stiffening member positioned adjacent to but discrete from the actuator, the second non-conducting stiffening member overlapping an other portion of the chamber and an other one of the opposed walls, the second non-conducting stiffening member having a width and a thickness sufficient to provide further additional stiffness to the membrane.

9. The printhead architecture as defined in claim 8, further comprising:

a first trace positioned on the first non-conducting stiffening member such that the first trace overlaps the portion of the chamber and a portion of the one of the opposed walls; and

a second trace positioned on the second non-conducting stiffening member such that the second trace overlaps the other portion of the chamber and a portion of the other one of the opposed walls.

10. The printhead architecture as defined in claim 8, further comprising:

a first trace positioned on the first non-conducting stiffening member such that the first trace does not overlap the portion of the chamber and does overlap a portion of the one of the opposed walls; and a second trace positioned on the second non-conducting stiffening member such that the second trace does not overlap the other portion of the chamber and does overlap a portion of the other one of the opposed walls.

11. The printhead architecture as defined in claim 8 wherein:

the die has a plurality of chambers formed therein such that the chambers are arranged in aligned columns and offset rows, each of the plurality of chambers being at least partially defined by respective opposed walls;

each of the plurality of chambers has a respective actuator associated therewith; and

each of the respective actuators in a single column has positioned adjacent thereto but discrete therefrom respective first and second non-conducting stiffening members.

12. The printhead architecture as defined in claim 11 wherein the respective first and second non-conducting stiffening members extend along respective offset rows.

13. The printhead architecture as defined in claim 11, further comprising at least one trace positioned on the respective first and second non-conducting stiffening members.

14. The printhead architecture as defined in claim 8 wherein:

the first non-conducting stiffening member and the second non-conducting stiffening member are each a dielectric material; and

the width of each of the first non-conducting stiffening member and the second non-conducting stiffening member ranges from about 2 μm to about 15 μm, and wherein the thickness of each of the first non-conducting stiffening member and the second non-conducting stiffening member ranges from about 10 nm to about 10 μm.

15. A method for increasing stiffness of a membrane of a printhead architecture including a chamber that is at least partially defined by opposed walls, the method comprising:

selecting a width and a thickness of a trace or a non-conducting stiffening member to provide additional stiffness to the membrane; and

positioning the trace or the non-conducting stiffening member having the selected width and thickness adjacent to but discrete from an actuator of the printhead architecture, the trace or the non-conducting stiffening member overlapping a portion of the chamber and one of the opposed walls.

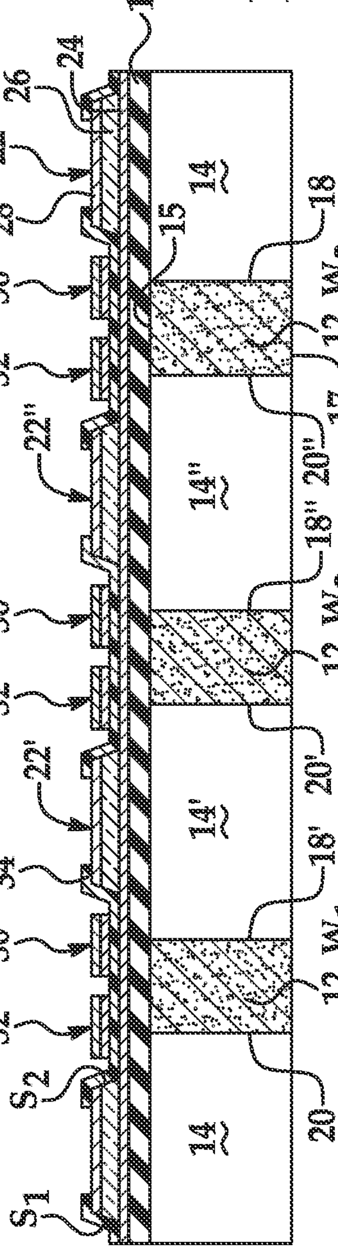


FIG. 1

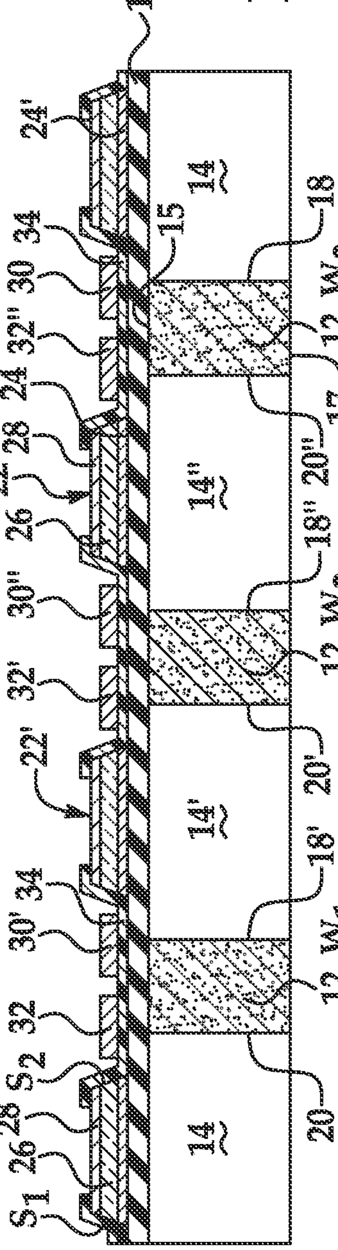


FIG. 2

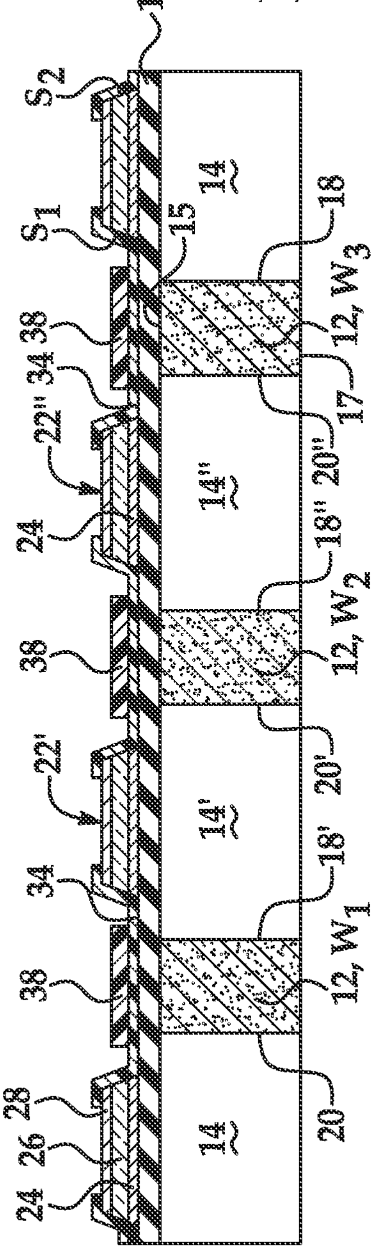
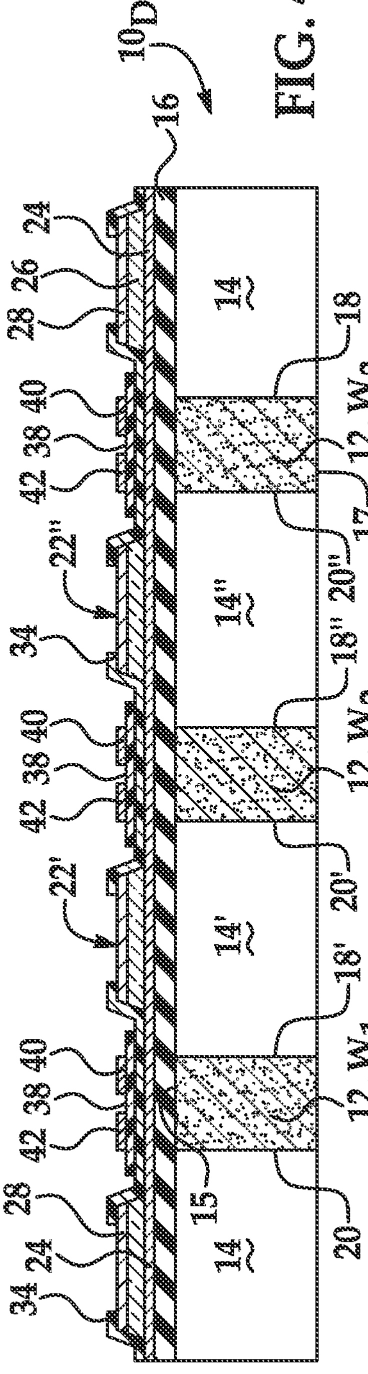


FIG. 3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28
40
38
42
22''
34
40
38
42
22'
40
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28
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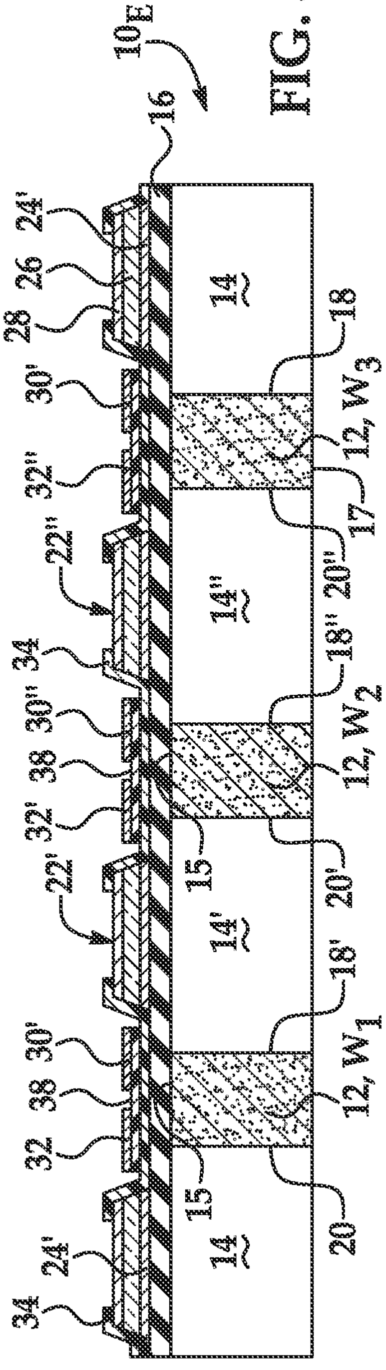
34
14
18
12, W3
17
20''
14''
18''
12, W2
20'
14'
18'
12, W1
15
20
14

FIG. 4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34
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38
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30'
38
32
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14
18
12, W3
17
20''
14''
18''
12, W2
15
20'
14'
18'
12, W1
15
20
14

FIG. 5

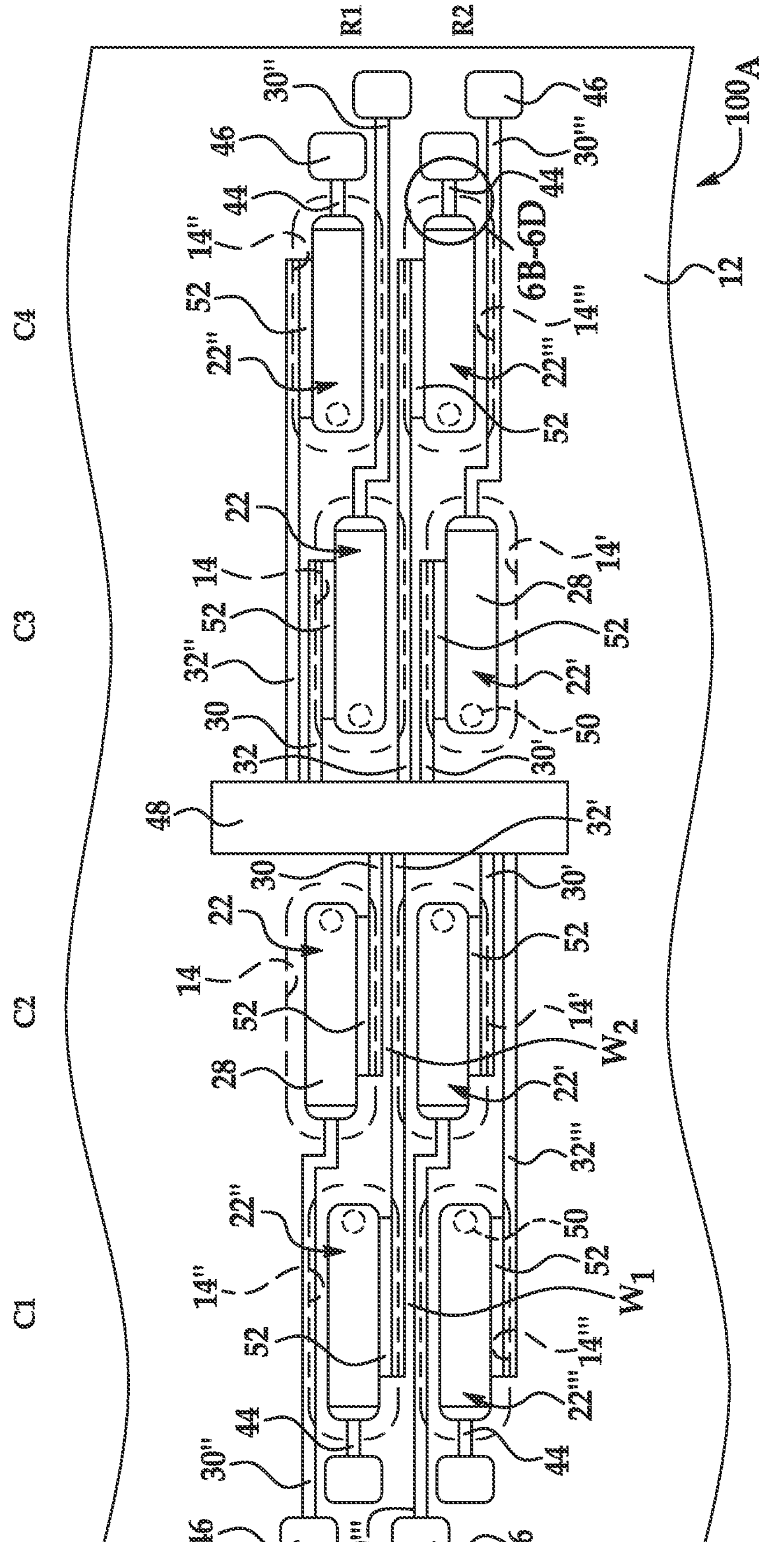

R1
R2
100A
C1
C2
C3
C4
12
14
14'
14''
14'''
22
22'
22''
22'''
28
30
30'
30''
30'''
32
32'
32''
32'''
44
46
48
50
52
W1
W2
6B-6D

FIG. 6A

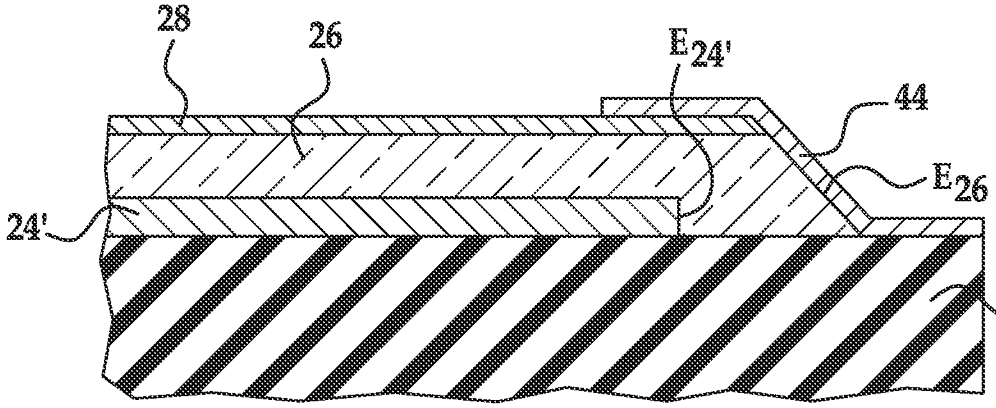


FIG. 6B

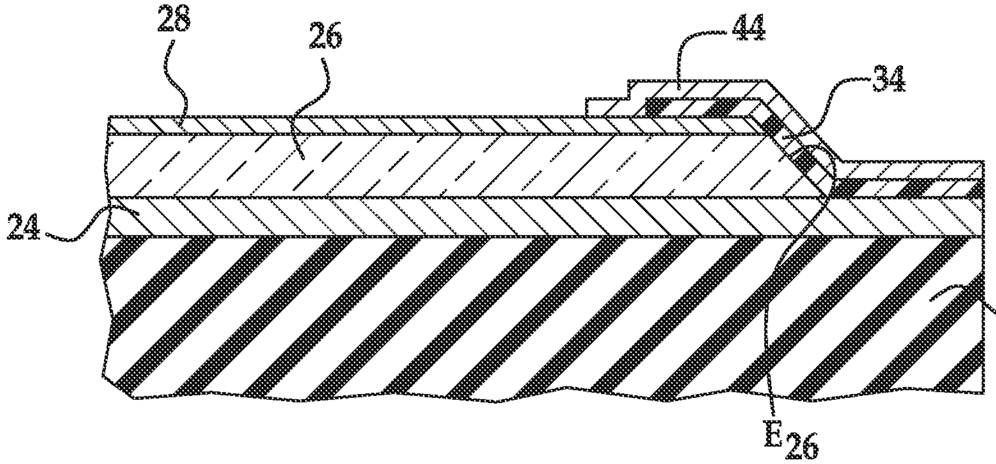


FIG. 6C

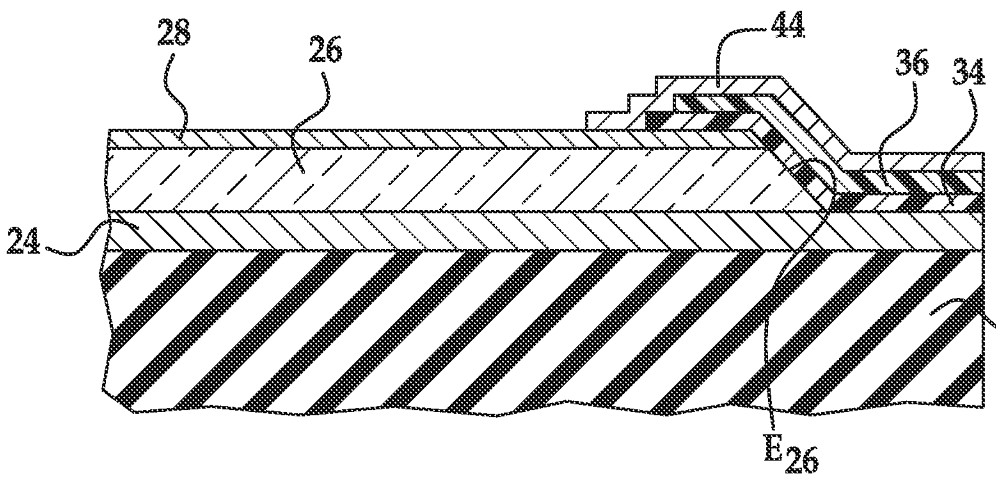


FIG. 6D

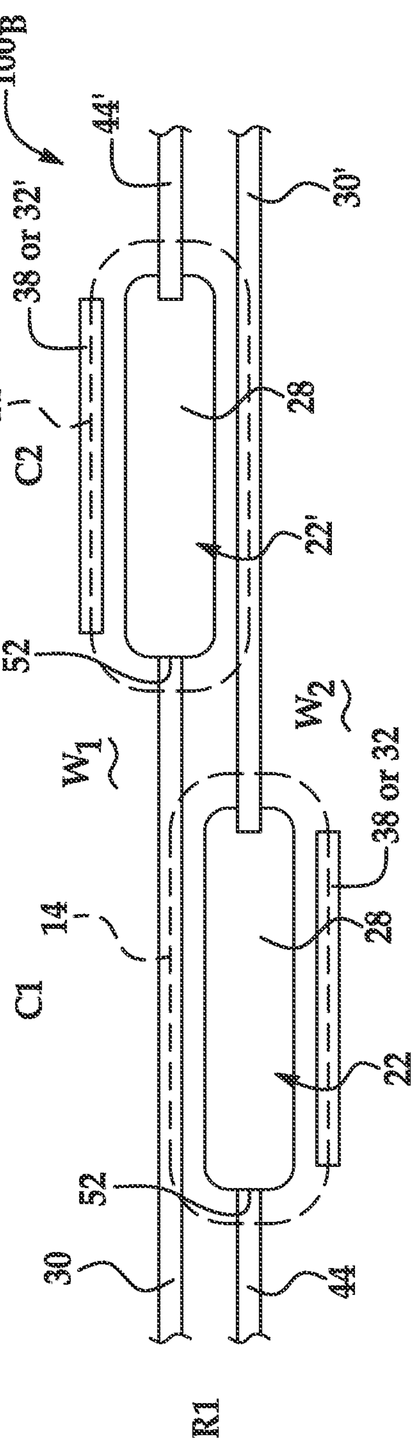
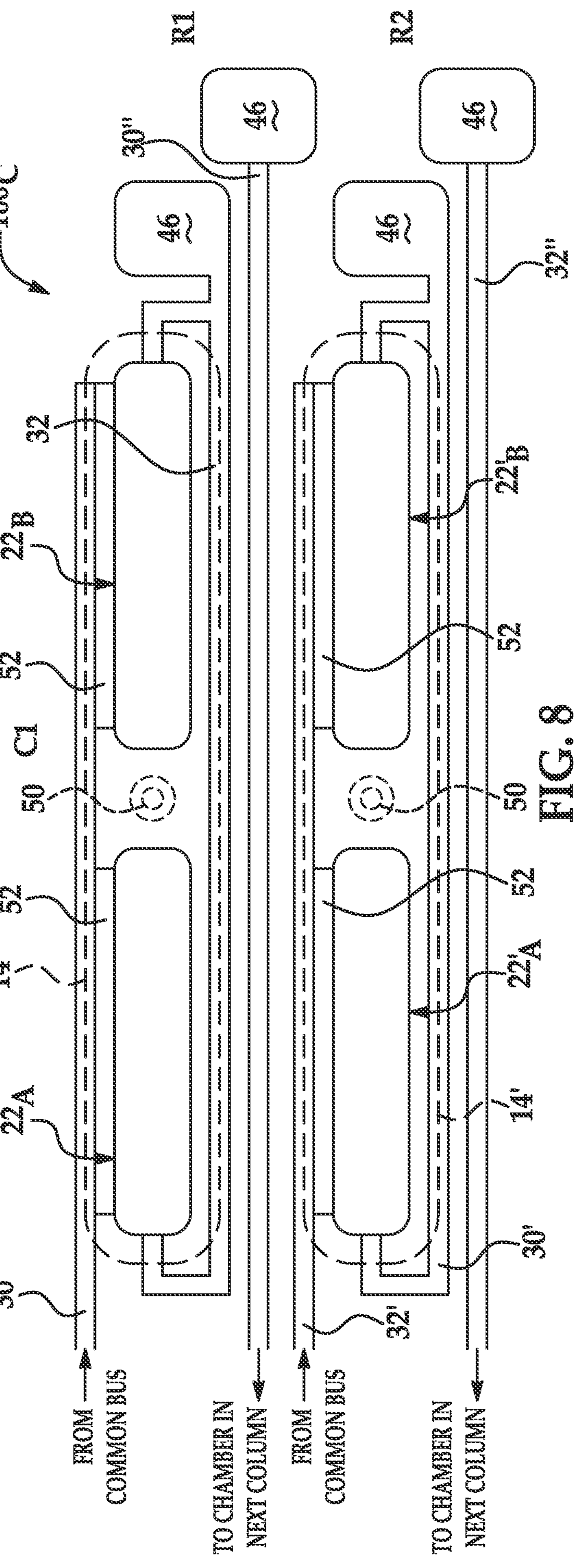

100B
44'
30'
38 or 32'
14'
C2
28
22'
52
W1
W2
38 or 32
C1
14
28
22
52
30
44
R1

FIG. 7


R1
R2
46
46
30''
100C
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46
32''
32
22B
22'B
52
52
C1
50
50
52
52
14
22'A
22A
14'
30
30'
32'
FROM COMMON BUS
TO CHAMBER IN NEXT COLUMN
FROM COMMON BUS
TO CHAMBER IN NEXT COLUMN

FIG. 8

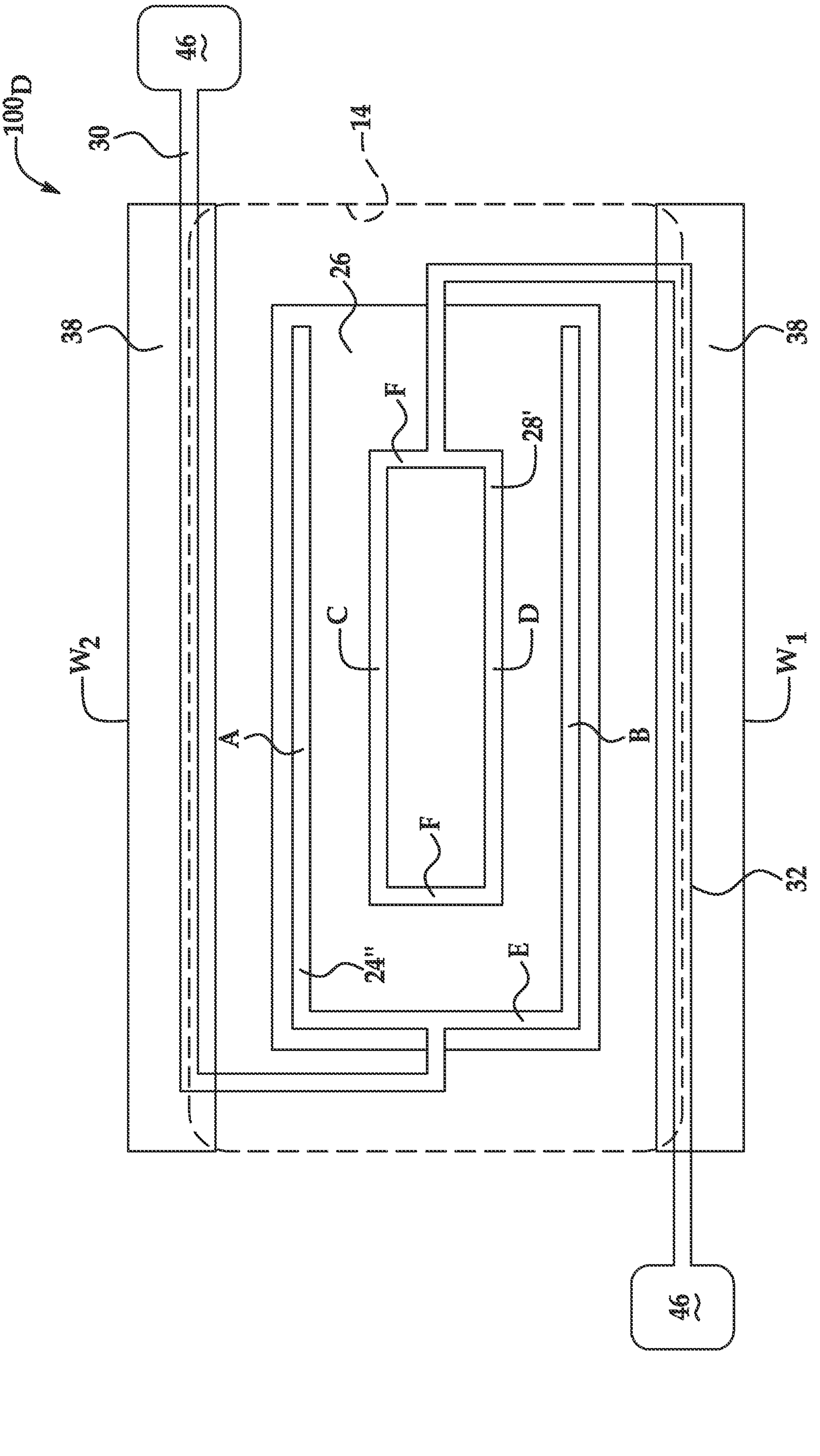

FIG. 9

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2012/044728

A. CLASSIFICATION OF SUBJECT MATTER

B41J 2/175(2006.01)i, B41J 2/045(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

B41J 2/175; B41J 2/055; H01L 41/04; B41J 2/045

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKOMPASS(KIPO internal) & Keywords: print, head, chamber, stiffness, electrode, piezoceramic, layer

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2008-0030551 A1 (MIYAZAWA et al.) 07 February 2008 See abstract, paragraphs [0086],[0087], and figure 11.	1-15
A	US 2010-0091075 A1 (MIYAZAWA et al.) 15 April 2010 See abstract, paragraphs [0027],[0036], and figure 2B.	1-15
A	JP 2000-326503 A (SEIKO EPSON CORP.) 28 November 2000 See abstract, paragraphs [0205],[0207], and figures 17,21.	1-15
A	US 2011-0074890 A1 (MIYAZAWA et al.) 31 March 2011 See abstract, paragraphs [0086]-[0088], and figure 10.	1-15

☐ Further documents are listed in the continuation of Box C.   ☒ See patent family annex.

* Special categories of cited documents:

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
22 FEBRUARY 2013 (22.02.2013)	**25 FEBRUARY 2013 (25.02.2013)**

Name and mailing address of the ISA/KR

Facsimile No. 82-42-472-7140

Authorized officer

PARK, Jin Ho

Telephone No. 0424818398

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