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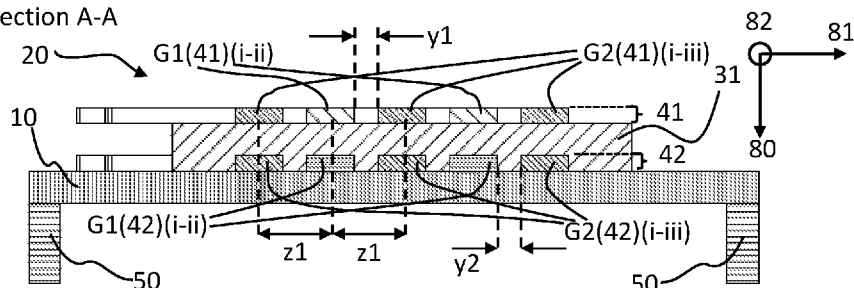
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Fig. 2D
Section A-A

(57) **Abstract:** An improved electrical element (20) is provided, comprising a ceramic member, wherein said ceramic member comprises at least one layer (31) having a depth; and first (41) and second (42) electrode layers disposed adjacent the at least one layer (31) of the ceramic member, such that a potential difference may be established through at least a portion of the ceramic member during operation. The electrical element (20) is arranged adjacent to a flexible membrane (10). The first electrode layer (41) comprises a first group of electrodes (G1(41)) comprising at least two fingers and a second group of electrodes (G2(41)) comprising at least one finger; the fingers of the first and second groups of electrodes (G1(41), G2(41)) are arranged alternately in the first electrode layer (41) in an interdigitation direction. The second electrode layer (42) comprises a first group of electrodes (G1(42)) comprising at least two fingers and a second group of electrodes (G2(42)) comprising at least one finger; the fingers of the first and second groups of electrodes (G1(42), G2(42)) are arranged alternately in the second electrode layer (42) in an interdigitation direction. For each group of electrodes (G1, G2) all the fingers in said group are electrically connected to each other and to a group electrical contact. The fingers of the first group of electrodes of the first electrode layer (G1(41)) at least partially overlap in the interdigitation direction with the corresponding fingers of the first group of electrodes of the second electrode layer (G1(42)); and the fingers of the second group of electrodes of the first electrode layer (G2(41)) at least partially overlap in the interdigitation direction with the corresponding fingers of the second group of electrodes of the second electrode layer (G2(42)). The group electrical contacts are arranged to be addressable to establish a potential difference between the fingers of the first (G1) and second (G2) groups of electrodes of the same electrode layer (41, 42) in the interdigitation direction and deformation of the ceramic member in d33 mode, and to be addressable to establish a potential difference in the depth direction between said at least partially overlapping fingers of the first and second groups of electrodes (G1, G2) of the first and second electrode layers (41, 42) and deformation of the ceramic member in d31 mode. Drive signals, suitable for driving said electrical element (20), switching circuits, controllers, and methods of driving the electrical element (2) are also provided.

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DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN,
HR, HU, ID, IL, IN, IR, IS, IT, JO, JP, KE, KG, KH, KN,
KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD,
ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO,
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ELECTRICAL ELEMENT

FIELD OF THE INVENTION

The present invention relates to an electrical element for a micro-electromechanical systems (MEMS) device, in particular, but not limited to, an electromechanical actuator or an electromechanical sensor. An electromechanical actuator may find particularly beneficial application as an actuator component for a droplet ejection head, such as an inkjet printhead.

BACKGROUND

Droplet ejection heads are now in widespread usage, whether in more traditional applications, such as inkjet printing, or in advanced applications, such as 3D printing, or other materials deposition or rapid prototyping techniques. Accordingly, the fluids used may have novel chemical properties to adhere to new substrates and/or to increase the functionality of the deposited material.

Recently, inkjet printheads have been developed that are capable of depositing ink directly onto ceramic tiles, textiles, or other substrates, with high reliability and throughput. This allows the patterns on the substrate to be customized to a customer's exact specifications, as well as reducing the need for a full range of printed products to be kept in stock.

In still other applications, MEMS actuator devices may be used to deposit fluids in chemical and biological applications, such as for assays and testing, and MEMS sensing devices may be used to measure properties such as fluid pressures.

So as to be suitable for new and/or increasingly challenging applications, electrical elements for MEMS devices such as actuators and sensors continue to evolve and specialise. However, while a great many developments have been made, there remains room for improvement.

Electrical elements for MEMS devices are commonly manufactured through the deposition of a series of layers arranged on a substrate, for example through one or more techniques known in the thin film technology field. A typical electrical element, such as that shown in Fig. 1A and Fig. 1B, may have a configuration where a thin film of a ceramic material showing ferroelectric behaviour, for example a piezoelectric material or a relaxor/ferroelectric crossover material, is interposed between two electrically conductive

layers, a bottom electrode and a top electrode. Such an electrical element is deposited layer by layer on a substrate; commonly a wafer accommodates a plurality of such arrays of electrical elements. The bottom electrode may be a common electrode or may be patterned to form arrays of individual electrodes, each associated with an individual electrical element.

- 5 The thin film of the ceramic material may or may not be patterned as well. Individual electrical elements, therefore, might comprise a patterned ceramic material thin film or a region of an unpatterned “common” ceramic material thin film. Individually addressable regions of the electrical elements may be defined by at least one of the electrodes being patterned such as to be individual to each electrical element. Electrical connection of the
- 10 electrical element to the drive circuitry may be ensured through the use of metal traces that are directly connected to the electrodes of the electrical element.

Commonly employed ceramic materials include lead based ceramics with perovskite structure, especially lead titanate zirconate (PZT), doped PZT and PZT based solid solutions. They may be deposited onto the substrate through a number of deposition techniques known

15 in the art, for example, sputtering, chemical vapour deposition (CVD), chemical solution deposition (CSD). In recent years, significant effort has been put into the development of lead-free alternative ceramic materials such as (K,Na)NbO₃-based materials, (Ba,Ca)(Zr,Ti)O₃-based materials and (Bi,Na,K)TiO₃-based materials.

One of the most important parameters of any such electrical element when

20 configured as an actuator is its efficiency: i.e. maximum displacement using as low a voltage as possible (or maximum displacement for greater sensitivity for a sensor). There are three major modes of operation for such an electrical element: d_{33} , d_{15} , d_{31} (for simplicity referred to throughout as d_{33} , d_{15} and d_{31}). Many MEMS actuators operate in d_{31} mode. Fig. 1A is a schematic diagram of a MEMS actuator operable in d_{31} mode, it depicts a cross-section

25 showing a general layout for a MEMS device 10 for a droplet ejection apparatus, where the MEMS device 10 may comprise an actuator component 102, which comprises an electrical element 120. The electrical element 120 is mounted on a substrate 110, a portion of which is free to move as a flexible membrane. In this case it is part of the roof of a fluid chamber 195. Fluid, such as ink, may be supplied to the fluid chamber 195, via the fluid ports 198

30 which have been cut or etched through a capping layer 103. The capping layer 103 may further comprise a cavity 106 over the electrical element 120. Such cavities may be sealed

in a fluid-tight manner so as to prevent fluid entering from the fluid chambers 195 and fluid ports 198 into the cavity 106.

In some devices, only inlet fluid port(s) 198 may be required. Other MEMS devices may operate in so-called through-flow mode, where fluid flows through the fluid chamber 195 from an inlet fluid port 198 to an outlet fluid port 198 with a proportion of the fluid being ejected via the nozzle 197 as a droplet when the electrical element 120 is actuated appropriately.

Fig. 1B is a schematic diagram of a portion of the cross-section of Fig. 1A depicting part of the actuator component 102. It can be seen that the electrical element 120 is arranged over the substrate layer 110. The electrical element 120 comprises a ceramic member 123 and bottom and top electrodes 121 and 122 respectively which are disposed adjacent to the ceramic member 123, such that a potential difference may be established between the bottom electrode 121 and the top electrode 122 and through the ceramic member 123 during operation. The bottom electrode is adjacent to the substrate layer 110. An electrical trace 160 provides an electrical connection to the top electrode 122. A further electrical trace is provided to electrically connect the bottom electrode 121 (not shown in Fig. 1B).

The actuator component 102 comprises several other layers, which may themselves be a single layer or may comprise a laminate of sub-layers. The layers, such as insulating layer 170, passivation layer 150 and intermediate layer 140, may have a variety of functions. The intermediate layer 140 may comprise, for example, stress gradient mitigating layers; barrier layers for preventing diffusion of ions between the ceramic member and the substrate; and/or adhesion layers to improve adhesion of the electrical element to the substrate. Such additional layers may comprise for example inorganic oxide or nitride layers, such as alumina, silica, silicon nitride, zirconia, tantala, hafnia and the like.

The ceramic member 123 extends in the XY plane and comprises thin film ceramic material, of any suitable type that exhibits ferroelectric behaviour, such as those materials described above. When an electric field is applied along the Z-direction, establishing a potential difference between the top and bottom electrodes 122, 121 and through the ceramic member 123, the ceramic material expands in the Z-direction (d33) and contracts in the X-Y – directions (d31). Because the electrical element 120 is attached to the substrate 110 (which comprises a part that is a flexible membrane), when the ceramic material is deformed the flexible membrane bends DOWN (in the negative Z-direction) into the fluid chamber

195 (shown schematically as a dashed line in Fig. 1A.). When the electrical field is removed, the ceramic material is no longer subject to a potential difference and it returns to its neutral (undeformed) state and position, moving the flexible membrane with it. By applying suitable drive waveforms, an electrical element 120 such as that in Fig. 1A and Fig. 1B can be used to eject droplets via the nozzle 197 as and when desired and thereby to print onto a substrate, for example. Typically MEMS actuator devices being used for droplet ejection comprise a plurality of such electrical elements and associated fluid chambers, generally arranged in a single row, or arrays comprising multiple rows, so that large areas of substrate can be addressed. A droplet ejection head, for example, may comprise multiple actuators and may itself be used singly or with a plurality of other droplet ejection heads to form part of a droplet ejection apparatus.

Instead of operating in d31 mode, some MEMS actuators operate in d33 mode, where, using suitably placed first and second electrodes, an electric field is applied along the X-direction, so as to establish a potential difference through the ceramic member in the X-direction. The ceramic material expands in the X-Y direction (d33) and contracts in the Z-direction (d31). The actuator bends UP (in the positive Z-direction) and the flexible membrane is likewise moved. Again, when the electrical field is removed, the ceramic member returns to its neutral state and position, as does the flexible membrane.

It may be understood that MEMS devices similar to those described above that operate in d33 or d31 mode can also be configured as sensors. For example, where an applied force (such as fluidic pressure) causes the flexible membrane to deflect and consequently to deform the ceramic member, electricity is generated in proportion to the movement. Suitable calibration data allows the MEMS device to be used as a sensor to measure such forces.

A constraint of such above-described MEMS actuators is that the maximum displacement for a given applied voltage is limited to that achievable by the deformation mode (d31 or d33) (and for a sensor the voltage generated is tied to the maximum displacement achievable by the deformation mode). It would be desirable to have an electrical element that has a greater total displacement range available for a given applied voltage, when used as an actuator, and greater displacement for greater sensitivity when used as a sensor.

A further feature of an actuator component 102 for a droplet ejection head such as that of Fig. 1A is that in some applications and driving schemes the actuator element may

be held in the deformed d31 position between jetting events, by applying suitable voltages to the electrodes 121, 122 so as to generate a potential field across the ceramic member 123. When a droplet ejection event is desired, a suitable drive waveform is supplied to the actuator such that the following sequence of events occurs: the potential field is removed (e.g. d31 deflection is switched OFF) and the actuator therefore returns to its neutral position, moving the flexible membrane with it. This increases the volume of the fluid chamber 195 thereby drawing fluid into the fluid chamber 195. The drive waveform then applies suitable voltages to the electrodes 121, 122 so as to re-establish the potential field across the ceramic member 123 and deform it in d31 mode once more (e.g. d31 deflection mode is switched ON) thereby moving the flexible membrane into the fluid chamber 195 and ejecting a droplet of fluid via the nozzle 197.

The advantage of such a method of operation is that it may mitigate against unwanted droplet ejection events as the first movement of the actuator causes a fluid chamber filling event, so provides greater performance stability. A disadvantage of such a method of droplet ejection is that the electrical element 120 is held in the deformed d31 position, with a holding voltage applied to it, between droplet ejection events. This applied holding voltage leads to higher power consumption, adding undesirable costs to operation. Further, it may cause excess heat in the actuator component 102, which may have to be compensated for and may lead to accelerated deterioration of actuator performance, for example due to prolonged stresses in the boundary regions of the flexible membrane. It would therefore be desirable to be able to use drive waveforms where the electrical element 120 does not consume power between droplet ejection events, except when being actuated for other reasons (such as for sensing purposes, nozzle clearance, or other non-droplet-ejecting functions, such as maintenance); for e.g. where the electrical element 120 can be positioned in its neutral undeformed state, without significant power consumption, between actuation events, whilst still being able to mitigate against unwanted droplet ejection events on start-up.

The present invention addresses the above requirements by providing an electrical element that will deform in both d31 and d33 modes and methods of driving or sensing with such an element with associated benefits for maximum displacements achievable and maximum sensing sensitivities achievable respectively. Further, the present invention provides suitable drive waveforms to drive such an electrical element, including drive waveforms and methods of operation where, if desired, the electrical element can be

operated so that it can be held in a neutral position so that it does not consume power except when being actuated (either for droplet ejection or for other purposes as described above).

SUMMARY

5 Aspects of the invention are set out in the appended independent claims, while particular variants of the invention are set out in the appended dependent claims.

The following disclosure describes, in one aspect, an electrical element comprising:
a ceramic member, wherein said ceramic member comprises at least one layer having
a depth; and

10 first and second electrode layers disposed adjacent the at least one layer of the ceramic member, such that a potential difference may be established through at least a portion of the ceramic member during operation;

wherein said electrical element is arranged adjacent to a flexible membrane, and

wherein the first electrode layer comprises a first group of electrodes comprising at
15 least two fingers and a second group of electrodes comprising at least one finger;

wherein the fingers of the first and second groups of electrodes are arranged alternately in the first electrode layer in an interdigitation direction; and

wherein the second electrode layer comprises a first group of electrodes comprising at least two fingers and a second group of electrodes comprising at least one finger;

20 wherein the fingers of the first and second groups of electrodes are arranged alternately in the second electrode layer in an interdigitation direction; and

wherein for each group of electrodes all the fingers in said group are electrically connected to each other and to a group electrical contact.

In a second aspect there is provided a drive signal for driving an electrical element
25 according to the first aspect.

In a third aspect there is provided a switching circuit for an electrical element according to the first aspect.

In a fourth aspect there is provided a controller for a switching circuit according to the third aspect.

30 In a fifth aspect there is provided a method of driving an electrical element according to the first aspect.

BRIEF DESCRIPTION OF THE DRAWINGS

Reference is now directed to the drawings, in which:

Fig. 1A is a schematic cross-section through a known electrical component showing a general layout for a known electrical element for a droplet ejection head;

5 Fig. 1B is a schematic cross-section through a portion of the electrical element of Fig. 1A;

Fig. 2A depicts a top view of an electrical element according to an embodiment mounted on a flexible membrane;

Fig. 2B is a side view of the embodiment of Fig. 2A;

10 Fig. 2C is a perspective view of the embodiment depicted in Fig. 2A;

Fig. 2D is a cross-section through the embodiment depicted in Fig. 2A along the line AA; and

Fig. 2E is a cross-section through the embodiment of Fig. 2A along the line BB;

15 Fig. 3A depicts a cross-section through an electrical element such as that of Fig. 2A where the groups of electrodes are shaded to show the applied voltages, which would lead to the ceramic member deforming in d33 mode;

Fig. 3B represents the two layers of electrodes of the electrical element of Fig. 3A;

20 Fig. 4A depicts a cross-section through an electrical element such as that of Fig. 2A where the groups of electrodes are shaded to show the applied voltages, which would lead to the ceramic member deforming in d31 mode;

Fig. 4B depicts the two layers of electrodes of an electrical element such as that in Fig. 4A;

25 Fig. 5A is a top view of an electrical element according to another embodiment; which comprises a ceramic member with at least two layers and where the electrical element also comprises a third electrode layer;

Fig. 5B is a side view of the embodiment of Fig. 5A;

Fig. 5C is a perspective view of the embodiment depicted in Fig. 5A;

Fig. 5D is a cross-section through the embodiment along the line AA indicated in Fig. 5A;

30 Fig. 5E is a cross-section through the embodiment along the line BB indicated in Fig. 5A;

Fig. 6A is a top view of an electrical element according to another embodiment, similar to that of Fig. 5A, but where the first groups of electrodes of the first and third electrode layers are electrically connected to each other and where the second groups of electrodes of the first and third electrode layers are electrically connected to each other;

5 Fig. 6B is a side view of the embodiment of Fig. 6A;

Fig. 6C is a perspective view of the embodiment depicted in Fig. 6A;

Fig. 6D is a cross-section through the embodiment along the line AA indicated in Fig. 6A;

10 Fig. 6E is a cross-section through the embodiment along the line BB indicated in Fig. 6A;

Fig. 6F is a perspective view of the first, second and third layers of electrodes and their electrical connections;

Fig. 7A is a cross-section through an electrical element such as that of Fig. 5 or Fig. 6 with the groups of electrodes shaded according to whether a first voltage V1 or a second voltage V2 is applied, the applied voltages cause the ceramic member to deform in d33 mode;

Fig. 7B represents the three layers of electrodes of the electrical element of Fig. 7A;

20 Fig. 8A is a cross-section through an electrical element such as that of Fig. 5 or Fig. 6 with the groups of electrodes shaded as to whether a first voltage V1 or a second voltage V2 is applied, the applied voltages cause the ceramic member to deform in d31 mode;

Fig. 8B represents the three layers of electrodes of the electrical element of Fig. 8A;

Fig. 9A depicts a switching arrangement for an electrical element such as that of Fig. 6 where a single finger in each group in each electrode layer is depicted and the voltages applied are such as to cause the ceramic member to deflect in d33 mode;

25 Fig. 9B depicts a switching arrangement for an electrical element similar to that of Fig. 9A where the voltages applied are such as to cause the ceramic member to deflect in d31 mode;

Fig. 10A depicts a drive signal that will cause a ceramic member to deform in d31 mode;

30 Fig. 10B depicts the displacement of an electrical element in response to the drive signal of Fig. 10A;

Fig. 10C depicts the voltages applied to an electrical element such as that of Fig. 6 in the first and third stages of the drive signal depicted in Fig. 10A;

Fig. 10D depicts the voltages applied to an electrical element such as that of Fig. 6 in the second stage of the drive signal depicted in Fig. 10A;

5 Fig. 11A depicts a drive signal for an electrical element that will cause a ceramic member to deform in d33 mode;

Fig. 11B depicts the displacement of an electrical element in response to the drive signal of Fig. 11A, starting from a neutral position, moving to a d33 deformation and back again;

10 Fig. 11C depicts the voltages applied to an electrical element such as that of Fig. 6 in the first and third stages of the drive signal depicted in Fig. 11A;

Fig. 11D depicts the voltages applied to an electrical element such as that of Fig. 6 in the second stage of the drive signal depicted in Fig. 11A;

Fig. 12A depicts a drive signal for an electrical element that will cause a ceramic
15 member to deform in a first mode comprising a move from neutral to d33 deformation to d31 deformation and back to neutral;

Fig. 12B depicts the displacement of an electrical element comprising a ceramic member in response to the drive signal of Fig. 12A;

Fig. 12C depicts the voltages applied to an electrical element such as that of Fig. 6
20 in the first and fourth stages of the drive signal depicted in Fig. 12A;

Fig. 12D depicts the voltages applied to an electrical element such as that of Fig. 6 in the second stage of the drive signal depicted in Fig. 12A;

Fig. 12E depicts the voltages applied to an electrical element such as that of Fig. 6 in the third stage of the drive signal depicted in Fig. 12A;

25 Fig. 13A depicts a drive signal that will cause an electrical element to deform in a second mode comprising a move from d31 deformation to d33 and back to d31;

Fig. 13B depicts the displacement of an electrical element comprising a ceramic member in response to the drive signal of Fig. 13A;

Fig. 13C depicts the voltage applied to an electrical element such as that of Fig. 6 in
30 the first and third stages of the drive signal depicted in Fig. 13A;

Fig. 13D depicts the voltage applied to an electrical element such as that of Fig. 6 in the second stage of the drive signal depicted in Fig. 13A;

Fig. 14A depicts a drive signal for an electrical element that will cause an electrical element to deform in a third mode comprising a move from a neutral position to d31 mode to d33 mode, back to d31 mode and then to a neutral position;

Fig. 14B depicts the displacement of an electrical element comprising a ceramic member in response to the drive signal of Fig. 14A;

Fig. 14C depicts the voltages applied to an electrical element such as that of Fig. 6 in the first and fifth stages of the drive signal depicted in Fig. 14A;

Fig. 14D depicts the voltages applied to an electrical element such as that of Fig. 6 in the second and fourth stages of the drive signal depicted in Fig. 14A;

Fig. 14E depicts the voltages applied to an electrical element such as that of Fig. 6 in the third stage of the drive signal depicted in Fig. 14A;

Fig. 15A depicts a drive signal for an electrical element that will cause an electrical element to deform in a fourth mode comprising a move from d31 deformation to a neutral position, to d33, back to a neutral position and back to d31 deformation;

Fig. 15B depicts the displacement of an electrical element in response to the drive signal of Fig. 15A;

Fig. 15C depicts the voltages applied to an electrical element such as that of Fig. 6 in the first and fifth stages of the drive signal depicted in Fig. 15A;

Fig. 15D depicts the voltages applied to an electrical element such as that of Fig. 6 in the second and fourth stages of the drive signal depicted in Fig. 15A;

Fig. 15E depicts the voltages applied to an electrical element such as that of Fig. 6 in the third stage of the drive signal depicted in Fig. 15A;

Fig. 16 depicts various electrical elements with alternative arrangements for the electrodes.

In the Figures, like features are indicated by like reference numerals throughout. It should be noted that the drawings are not to scale and that certain features may be shown with exaggerated sizes so that these are more clearly visible.

DETAILED DESCRIPTION

Embodiments of the invention and their variants will now be described with reference to Figs. 2 to 9 and methods of driving and drive signals will be described with reference to Figs. 9 to 15.

Two layer device

Fig. 2A depicts a top view of an electrical element 20 according to an embodiment mounted on the flexible membrane 10. The electrical element 20 comprises a ceramic member 30 and first and second electrode layers 41, 42. The electrical element 20 is arranged adjacent to a flexible membrane 10 as part of a MEMS device 100. Fig. 2B is a side view of the embodiment of Fig. 2A; Fig. 2C is a perspective view of the embodiment depicted in Fig. 2A; Fig. 2D is a cross-section through the embodiment depicted in Fig. 2A along the line AA; and Fig. 2E is a cross-section through the embodiment depicted in Fig. 2A along the line BB.

It can be seen from Figs. 2A-2E that the first and second electrode layers 41, 42 each comprise first and second groups of electrodes G1(41),G2(41),G1(42),G2(42) respectively. It can further be seen from, for example, Fig. 2D that each group of electrodes comprises a plurality of fingers G1(41)(i-ii),G2(41)(i-iii),G1(42)(i-ii),G2(42)(i-iii). It can further be seen that all the fingers in each group of electrodes G1(41),G2(41),G1(42),G2(42) are electrically connected to each other by a common connector C1(41),C2(41),C1(42),C2(42) respectively. The common connectors are then each electrically connected to a respective group electrical contact i.e. C1(41) to OL, C2(41) to OR, C1(42) to IL, and C2(42) to IR. Electrical connection of the electrical element to the drive circuitry may be ensured through the use of metal traces that are directly connected to the group electrical contacts OL,OR,IL,IR of the electrical element.

The ceramic member 30 is shown in Figs. 2A-2E as comprising a single layer 31, but this is by no means limiting and the ceramic member 30 may comprise a plurality of layers 31(i-n) such that there is an electrical element 20 comprising a ceramic member 30; where the ceramic member 30 comprises at least one layer 31 having a depth (in the depth direction 80). The first and second electrode layers 41,42, are disposed adjacent to the at least one layer 31 of the ceramic member 30, such that a potential difference may be established through at least a portion of the ceramic member 30 during operation. The electrical element 20 is arranged adjacent to a flexible membrane 10. Put another way, as shown in Fig. 2, in this embodiment the first and second electrode layers 41,42 are arranged on opposite sides of the ceramic member 30, where in this embodiment the ceramic member

30 comprises a layer 31, though it may be understood that this is not limiting and the ceramic member 30 may comprise a plurality of layers.

The first electrode layer 41 comprises a first group of electrodes G1(41) comprising two fingers G1(41)(i-ii) and a second group of electrodes G2(41) comprising three fingers G2(41)(i-iii). The fingers of the first and second groups of electrodes G1(41), G2(41) are arranged to fit together alternately (interdigitate) in the first electrode layer 41 in the interdigitation direction 81. It can be seen that there is a gap y1 between alternate fingers in the electrode layer, such that they don't touch each other. Likewise the second electrode layer 42 comprises a first group of electrodes G1(42) comprising two fingers G1(42)(i-ii) and a second group of electrodes G2(42) comprising three fingers G2(42)(i-iii). The fingers of the first and second groups of electrodes G1(42), G2(42) are arranged alternately in the second electrode layer 42 in the interdigitation direction 81. It can be seen from Fig. 2D that in this arrangement each of the gaps y1 between alternate fingers in the second electrode layer 42 is filled with material that comprises part of the layer 31.

For each group of electrodes all of the fingers in the group are electrically connected to each other (e.g. via the common connectors C1(41), C2(41), C1(42), C2(42) respectively) and respectively electrically connected to a group electrical contact OL, OR, IL, IR.

As can be seen from Fig. 2D the fingers of the first group of electrodes G1(41) of the first electrode layer 41 are arranged such that they overlap in the interdigitation direction 81 with corresponding fingers of the first group of electrodes G1(42) of the second electrode layer 42 on the other side of the ceramic member 30, for e.g. finger G1(41)(i) overlaps finger G1(42)(i) and likewise for the remaining fingers in the groups of electrodes G1(41), G1(42). Similarly the fingers of the second group of electrodes G2(41) of the first electrode layer 41 overlap in the interdigitation direction 81 with the corresponding fingers of the second group of electrodes G2(42) of the second electrode layer 42, for e.g. finger G2(41)(i) overlaps finger G2(42)(i) etc.

The electrodes of corresponding group pairs may at least partially overlap, preferably they overlap by at least 50% in the interdigitation direction 81; more preferably they may overlap by more than 50%, still more preferably they may overlap by 90% or more. The centre-to-centre spacing Z1 (as depicted in Fig. 2D) may be substantially constant. Maintaining the centre-to-centre spacing Z1 close to constant may enable the electrodes to be substantially aligned and maximise the overlap region between corresponding fingers in

the groups and layers. As can be seen from Figs. 2D and 2E, in this embodiment the depth direction 80 and the interdigitation direction 81 are perpendicular to each other. As can also be seen from Figs. 2D and 2E, the second electrode layer 42 is closer to the flexible membrane 10 than the first electrode layer 41.

5 It may be understood that the layer 31 of the ceramic member 30 may be formed by depositing a plurality of sub-layers, for example by chemical vapour deposition (CVD), chemical solution deposition (CSD), sol-gel deposition, etc. so as to build up multiple layers to form a ceramic member of a desired thickness. It may be understood that as used herein ceramic material comprises a ceramic material exhibiting ferroelectric behaviour, examples
10 of which are discussed above.

The flexible membrane 10 is fixedly attached to supports 50. It may be understood that whilst the supports 50 are shown along two sides of the flexible membrane 10, depending on the device in which the electrical element 20 is used and the location in the device there may be continuous supports along the other two sides, or discontinuous supports
15 or supports with openings so as to allow a fluid, for example, to enter the space adjacent to the flexible membrane. For example, the electrical element 20 of Figs. 2A-2E could be used as an actuator element in the droplet ejection head actuator component of Fig. 1A instead of the known arrangement. It may further be understood that the supports 50 are merely shown schematically and in practise any suitable arrangement may be used to support the flexible
20 membrane 10 such that it can move as required.

Turning now to Fig. 3A, this depicts a cross-section through an electrical element 21, similar to that of Figs. 2A-2E, except that the first groups of electrodes G1(41),G1(42) both comprise three fingers rather than two. Figs. 3A-3B depict how voltages may be applied to drive the electrical element 21 as an actuator element. For simplicity, much of the detail
25 of Figs. 2A-2E has been omitted from Figs. 3A-3B. In Figs. 3A-3B, the groups of electrodes G1(41),G2(41),G1(42),G2(42) have been shaded to indicate whether they are at a first voltage V1 (grey) or a second voltage V2 (black). It can be seen that alternate columns 91, 92 of electrode fingers in the interdigitation direction 81 are at a first voltage V1 or at a second voltage V2, e.g. the first column 91(i) comprises G1(41)(i),G2(41)(i) at the second
30 voltage V2 and the second column 92(i) comprises G2(41)(i) and G2(42)(i) at the first voltage V1, with the pattern repeating in the interdigitation direction 81.

In the example of Fig. 3A, the groups of electrodes have been chosen and the voltages applied to them such that the ceramic member 30 will deform in d33 mode. Fig. 3B depicts an exploded top view of the first and second electrode layers 41, 42 of the electrical element 21 of Fig. 3A, with the ceramic member 30 omitted. Fig 3B also depicts the common connectors C1(41),C2(41),C1(42),C2(42) and the group electrical contacts OL,OR,IL and IR. The groups of electrodes G1(41),G2(41),G1(42),G2(42), their respective connectors C1(41),C2(41),C1(42),C2(42) and the group electrical contacts OL,OR,IL and IR have, as in Fig. 3A, been shaded to show whether a first voltage V1 (grey) or a second voltage V2 (black) has been applied to them.

It can be seen from both Fig. 3A and Fig. 3B that in each electrode layer 41,42 the first groups of electrodes G1(41),G1(42) are at a second voltage V2 (black) and the second groups of electrodes G2(41),G2(42) are at a first voltage V1 (grey). Where there is a voltage difference between the second voltage V2 and the first voltage V1 (e.g. $V2 > V1$) such a configuration will create an effective potential field in the ceramic member 30 aligned with the interdigitation direction 81 and cause the ceramic member 30 to deform in d33 mode and bend UP with respect to the depth direction 80 as indicated by the dashed line L33 in Fig. 3A. By effective it may be understood that the effective potential field is an average of all the fields developed between the respective fingers of the groups that are differently charged.

For simplicity, the flexible membrane 10 and the supports 50 are not depicted in Fig. 3A or Fig. 3B, but it may be understood that where there is a flexible membrane 10 arranged adjacent to and fixedly connected to the electrical element 21 (e.g. as shown in Fig. 2), the deformation of the ceramic member 30 in d33 mode will likewise move the flexible membrane 10 UP with respect to the depth direction 80. It may be understood that because the flexible membrane 10 is fixedly attached to the supports 50 and to the electrical element 21, the supports will constrain the movement of the flexible membrane 10, such that the maximum displacement will occur furthest from the supports 50, as shown by the line L33 (e.g. generally in the centre).

Fig. 4A depicts a cross-section through an electrical element 21 such as that of Fig. 3A except that the groups of electrodes have been chosen such that the applied first and second voltages V1,V2 would lead to the ceramic member 30 deforming in d31 mode. Fig. 4B represents an exploded top view of the first and second electrode layers 41,42 of the

electrical element 21 of Fig. 4A. As for Fig. 3, the groups of electrodes, common connectors and the group electrical contacts of Fig. 4 have been shaded to show whether a first voltage V1 or a second voltage V2 is applied to them.

It can be seen from both Fig. 4A and 4B that in a first electrode layer 41, the first and second groups of electrodes G1(41),G2(41) are both at a first voltage V1 and in a second electrode layer 42, the first and second groups of electrodes G1(42),G2(42) are both at a second voltage V2. To put this another way, in Fig. 4A it can be seen that all the fingers in a given electrode layer 41,42 are at the same voltage, whilst in Fig. 3A the voltages applied to the fingers alternate in columns 91,92, in the interdigitation direction 81.

Where there is a voltage difference between the second voltage V2 and the first voltage V1 (e.g. $V2 > V1$) such a configuration will create an effective potential field in the ceramic member 30, in the case depicted in Fig. 4, the effective potential field is aligned with the depth direction 80, and causes the ceramic member 30 to deform in d31 mode and bend DOWN in the depth direction 80 as indicated by the dashed line L31. As in Fig. 3, the flexible membrane 10 and the supports 50 are not depicted in Fig. 4 but it may be understood that deformation of the ceramic member 30 in d31 mode will likewise cause the flexible membrane 10 to be moved DOWN in the depth direction 80.

It may be understood that by applying suitable drive signals to chosen groups from the groups of electrodes G1(41),G2(41),G1(42),G2(42) by addressing their respective group electrical contacts OL,OR,IL,IR, the ceramic member 30 can be driven to deform in d33 and/or d31 mode and where the electrical element 21 is attached to a flexible membrane, this can be used to create an electromechanical actuator to use, for example, in a droplet ejection head to eject droplets from a fluid chamber.

It may also be understood that as an alternative, for example where fluid pressures in a fluid adjacent to a flexible membrane 10 cause it to deflect, and hence deform the ceramic member 30, then the electrical element 20,21 may be used as a sensor, as the deformation of the ceramic member 30 in d31 and/or d33 mode will generate an electrical signal or (where the pressure is fluctuating) signals. The sensor may be used with suitable calibration data to measure pressures in the fluid, for example. As a further example, the electromechanical actuator in a fluidic device, such as a droplet ejection head, may be used in idle times when not ejecting droplets to measure and monitor fluidic properties, e.g. it may be used as a sensor when not being used as an actuator. Still further, lower voltage

signals could be sent to an electrical element 20,21 when idle, to cause smaller deflections that are insufficient to eject fluid droplets, for example, in order to determine properties of the actuator such as to track any changes in actuator performance with age (e.g. degradation) or to check for actuator non-responsiveness.

5

Method

As an example, using the electrical element 20,21 as an electrical actuator element 20,21 a method of driving the electrical actuator element 20,21 may be as follows, wherein the electrical actuator element 20,21 comprises a ceramic member 30. The ceramic member
10 30 comprises at least one ceramic layer 31 having a depth and first and second electrode layers 41,42 disposed adjacent to the at least one ceramic layer 31 in the depth direction 80, such that a potential difference may be established through at least a portion of the ceramic layer during operation. The electrical actuator element 20 is arranged adjacent to a flexible membrane 10.

15 The first electrode layer 41 comprises a first group of electrodes G1(41) and a second group of electrodes G2(41); and the fingers of the first and second group of electrodes G1(41), G2(41) are arranged alternately in the first electrode layer 41 in an interdigitation direction 81. The second electrode layer 42 comprises a first group of electrodes G1(42) and a second group of electrodes G2(42). The fingers of the first and second group of electrodes
20 G1(42), G2(42) are arranged alternately in the second electrode layer 42 in the interdigitation direction 81.

For each group of electrodes G1(41),G2(41),G1(42),G2(42), all the fingers in a given group are electrically connected to each other and to a group electrical contact OL,OR,IL,IR; and the first group of electrodes G1(41) of the first electrode layer 41 at least partially
25 overlap in the interdigitation direction 81 with the first group of electrodes G1(42) of the second electrode layer 42. The second group of electrodes G2(41) of the first electrode layer 41 at least partially overlap in the interdigitation direction 81 with the second group of electrodes G2(42) of the second electrode layer 42.

By choosing respective groups of electrodes so as to establish a potential difference
30 through at least a portion of the ceramic member 30 (for example between the respective chosen groups of electrodes), the ceramic member 30 can be deformed in d31 mode or d33 mode. The method comprises choosing the deformation mode or a sequence of deformation

modes and supplying at least two drive signals to the ceramic member 30 by addressing the respective group electrical contacts OL,OR,IL,IR, so as to establish a potential difference between the chosen respective groups of electrodes, so as to deform the ceramic member 30 in the chosen deformation mode or the chosen sequence of d31 and/or d33 deformation modes and thereby moving the flexible membrane.

Using an electrical element that can deform in both d33 and d31 mode and using methods of driving to deform such that an electrical element in d33 and/or d31 mode may be used to increase the maximum displacement achievable for a given applied voltage, since the ceramic member 30 can be moved both UP and DOWN relative to the depth direction

80. This increased maximum displacement of the ceramic member 30 increases the maximum actuation range of the electrical actuator element 20,21. For example, in a droplet ejection apparatus this increases the displaced volume of fluid achievable in the fluid chamber and hence may increase the maximum droplet size achievable. The greater maximum displaced volume achievable may also have the beneficial effect of enabling fluids with higher viscosities to more readily be ejected, extending the range of ejectable fluids.

Alternatively, a lower applied voltage may be used to achieve the same displacement as a known electrical element, such as that in Fig. 1A, which may have beneficial effects on the lifetime achievable for the electrical element and hence for fluidic MEMS devices such as droplet ejection heads that incorporate such electrical elements 20,21. Still further, operating the ceramic member 30 in d33 and d31 mode may allow the use of materials with lower overall performance, by increasing the maximum displacement achievable with such materials. This may be beneficial if such materials are desirable for use due to other advantages such as reduced costs of manufacture, or better environmental credentials (such as lead-free materials).

A method to deform the electrical actuator element 20,21 in d31 mode from an undeformed or neutral position (the neutral position is where the ceramic member 30 is not subject to a potential difference, e.g. because the applied voltages are rest voltages or zero, or else because the ceramic member 30 is not subject to any applied voltages) may comprise supplying a first voltage V1 to the first and second groups of electrodes G1(41),G2(41) in the first electrode layer 41 and supplying a second voltage V2 to the first and second groups of electrodes G1(42),G2(42) in the second electrode layer 42. This is shown in Fig. 4A,

where all the electrodes in the first electrode layer 41, in both groups G1(41),G2(41) are at voltage V1 (shaded grey) and all the electrodes in the second electrode layer 42 in both groups G1(41),G2(41) are at voltage V2 (shaded black). As it may be understood, the first group of electrodes G1(41) may be connected via the first group electrical contact OL and the first common connector C1(41) and the second group of electrodes G2(41) may be connected via the second group electrical contact OR and the second common connector C2(41). Similarly, the first group of electrodes G1(42) may be connected via the third group electrical contact IL and the first common connector C1(42) and the second group of electrodes G2(42) may be connected via the fourth group electrical contact IR and the second common connector C2(42). The potential difference established by this arrangement would be in the depth direction 80.

When the second voltage V2 is greater than the first voltage V1, then the application of the voltages as described above may cause the ceramic member 30 to deform DOWN in the depth direction 80 in d31 mode, as shown with a dotted line L31 in Fig. 4A. If the first and second voltages V1,V2 are maintained for a duration d, then the ceramic member 30 and hence the electrical actuator element 20,21 will be held in the deformed d31 mode position for the duration d. For example, the first drive signal may be at the first voltage V1 and the second drive signal may be at the second voltage V2.

A method to deform the electrical actuator element 20,21 in d33 mode from an undeformed or neutral position may comprise supplying the first group of electrodes G1(41) in the first electrode layer 41 and the first group of electrodes G1(42) in the second electrode layer 42 with a first voltage V1 [via the first group electrical contact OL and the third group electrical contact IL respectively] and supplying the second group of electrodes G2(41) in the first electrode layer 41 and the second group of electrodes G2(42) in the second electrode layer 42 with a second voltage V2 [via the second group electrical contact OR and the fourth group electrical contact IR respectively]. This is shown in Fig. 3A, where all the electrodes in the first groups G1(41),G1(42) of the respective first and second electrode layers 41,42 are at voltage V2 (shaded black) and all the electrodes in the second groups G2(41),G2(42) of the respective first and second electrode layers 41,42 are at voltage V1 (shaded grey) e.g. as previously described the voltages V1,V2 applied to the fingers alternate in columns 91,92, in the interdigitation direction 81. Such an arrangement would create an effective potential field in the interdigitation direction 81.

When the second voltage V2 is greater than the first voltage V1, then the application of the voltages V1,V2 (e.g. as first and second drive signals as described above) may cause the ceramic member 30 to deform UP in d33 mode, as shown with a dotted line L33 in Fig. 3A. If the first and second voltages V1,V2 are maintained for a duration d, then the ceramic member 30 and hence the electrical actuator element 20,21 will be held in the deformed d33 mode position for the duration d. The first voltage V1 may be a reference voltage, for example, a ground voltage.

It may be understood that by choosing respective groups of electrodes so as to establish a potential difference between the respective groups of electrodes, the ceramic member 30 can be deformed in d31 mode or d33 mode or in a chosen sequence of d31 and/or d33 modes, providing greater operational flexibility to the use of the electrical actuator element 20,21. It may further be understood that such a sequence may further comprise stages in the sequence where the ceramic member 30 is at the neutral position.

As previously described, when the electrical actuator element 20,21 is fixedly connected to a flexible membrane 10, deforming the ceramic member 30 moves the flexible membrane 10 with it. The electrical actuator element 20,21 may be arranged adjacent to the flexible membrane 10 that forms part of a fluid chamber wall in a fluidic MEMS device such as a droplet ejection apparatus, where the fluid chamber further comprises a fluid inlet and a nozzle.

In some embodiments, the fluid chamber may further comprise a fluid outlet, so that the fluid chamber can be used in a so-called throughflow mode (e.g. in an arrangement similar to that of Fig. 1A). In such droplet ejection apparatus (whether throughflow or not), the method may comprise driving the electrical actuator element 20,21 to deform in d33 or d31 mode, and/or a sequence of d33 and/or d31 modes, so as to move the flexible membrane 10 so as to eject a droplet via the nozzle. A droplet ejection apparatus may comprise a plurality of such fluid chambers, which may be arranged in an array so as to eject a chosen sequence of droplets at given positions as individual electrical actuator elements 20,21 are activated as required using the above methods. Such methods may be used to print onto a substrate where the droplet ejection apparatus is configured as a droplet ejection head, such as an inkjet printhead.

It may be understood that for some applications, holding the electrical actuator element 20,21 bent DOWN in the deformed d31 mode position may be desirable. For

example, in an electrical actuator element for a droplet ejection apparatus, where the flexible membrane 10 forms part of the wall of a fluid chamber, holding the electrical actuator element 20,21 deformed DOWN in d31 mode moves the flexible membrane 10 into the fluid chamber and reduces the fluid chamber volume.

5 A droplet ejection cycle may then comprise releasing the d31 deformation (for example, by switching V1 and V2 off, such that there is no potential difference across the ceramic member 30). The electrical actuator element 20,21 may then return to a neutral position and draw the flexible membrane 10 with it, increasing the fluid chamber volume and drawing in additional fluid (DRAW) and then a subsequent reapplication of the d31
10 deformation may decrease the fluid chamber volume and cause some of the fluid to be ejected out of the nozzle (PUSH). It may therefore be desirable in some droplet ejection cycles to apply holding signal(s) for a length of time prior to or after an actuation event so as to hold the ceramic member 30 in a d31 deformed position in readiness for a first or subsequent actuation event, such as a droplet ejection event.

15 As such, a method to deform and hold the ceramic member in deformed d31 mode may comprise supplying a first holding signal at a first voltage V1 and a second holding signal at a second voltage V2 wherein the method comprises supplying the first holding signal to the first and second groups of electrodes G1(41), G2(41) in the first electrode layer 41 [via the first group electrical contact OL and the second group electrical contact OR
20 respectively] and supplying the second holding signal to the first and second groups of electrodes G1(42), G2(42) in the second electrode layer 42 [via the third group electrical contact IL and the fourth group electrical contact IR respectively] so as to deform the ceramic member 30 in d31 mode and hold it in position, and likewise the electrical element 20,21 and the flexible membrane 10.

25 In some implementations, it may be desirable to hold the ceramic member 30 in its neutral or undeformed state, where no potential difference is established across the ceramic member 30, prior to or between actuation events. In such a situation, the method may comprise supplying a holding signal or holding signals, to the first and second groups of electrodes G1(41),G2(41),G1(42),G2(42) in the first and second electrode layers 41,42. For
30 example, the holding signal(s) may all be at the first voltage V1 such that all the electrodes are at the first voltage V1. Alternatively, such a method may comprise supplying no signal

to any of the groups of electrodes G1(41),G2(41),G1(42),G2(42), e.g. by switching off the voltage signal(s).

In an electrical actuator element for a droplet ejection apparatus, where the flexible membrane 10 forms part of the wall of a fluid chamber, deforming the ceramic member UP in d33 mode moves the flexible membrane 10 away from the fluid chamber, increasing the fluid chamber volume and drawing in additional fluid. Such a step may be used in preparation for a droplet ejection event and in a similar manner to that described for d31 deformation above, suitable holding signal(s) may be used to deform the ceramic member 30 in d33 mode and hold it in position.

Such a method may comprise a first holding signal at the first voltage V1 and a second holding signal at the second voltage V2, where the method comprises supplying the first holding signal to the second groups of electrodes G2(41),G2(42) in the first and second electrode layers 41,42 and supplying the second holding signal to the first groups of electrodes G1(41),G1(42) in the first and second electrode layers 41,42, so as to deform and hold the ceramic member 30 in d33 mode.

Three layer device, Fig. 5 & 6

Fig. 5A shows a top view of an electrical element 22 according to another embodiment, similar to the embodiment of Fig. 2A, such that like numerals have been used for like features where appropriate. In the embodiment of Fig. 5A (seen more clearly in Fig. 5B-5E), the electrical element 22 comprises a ceramic member 30 further comprising at least a second layer 32 having a depth (in the depth direction 80). The electrical element 22 further comprises a third electrode layer 43 and third groups of electrodes G1(43),G2(43).

Fig. 5B is a side view of the embodiment of Fig. 5A; Fig. 5C is a perspective view of the embodiment depicted in Fig. 5A; Fig. 5D is a cross-section through the embodiment depicted in Fig. 5A along the line AA; and Fig. 5E is a cross-section through the embodiment depicted in Fig. 5A along the line BB. The electrical element 22 comprises part of a MEMS device 101 that also comprises a flexible membrane 10 and supports 50.

As can be seen from Fig. 5D and Fig. 5E, the third electrode layer 43 comprises a first group of electrodes G1(43) comprising two fingers and a second group of electrodes G2(43) comprising three fingers; where the fingers of the first and second groups of electrodes G1(43),G2(43) are arranged alternately in the third electrode layer 43 in the

interdigitation direction 81; and where for each group of electrodes G1(43),G2(43) all the fingers in the respective group are electrically connected to each other (e.g. via the common connectors C1(43),C2(43) respectively) and the common connectors C1(43),C2(43) are electrically connected to a group electrical contact OL2,OR2; C1(43) is connected to OL2 and C2(43) is connected to OR2. As can further be seen from Fig. 5D, in this embodiment the third electrode layer 43 is closer to the flexible membrane 10 than the first electrode layer 41, and also closer to the flexible membrane 10 than the second electrode layer 42. To clarify, as shown in Fig. 5, the first and third electrode layers 41,43 are arranged on opposite sides of the ceramic member 30, with layer 31 of the ceramic member separating first and second electrode layers 41,42 and the second layer 32 of the ceramic member 30 separating second and third electrode layers 42,43. The third electrode layer 43 is arranged adjacent to the flexible membrane 10.

Such a three-layer arrangement may allow for greater complexity of driving schemes, since all three layers of electrodes 41,42,43, or two out of the three layers of electrodes could be driven, depending on the drive signals provided to the group electrical contacts OL,OR,IL,IR,OL2,OR2. For example, the electrical element 22 could be configured such that all three layers of electrodes could be driven when, for example, the electrical element 22 is being used to eject droplets from a fluid chamber, whilst two of the three layers of electrodes could be driven to test the electrical element 22's performance (e.g. to check for ageing effects or damage) without causing sufficient displacement of the flexible membrane to eject a droplet. Additionally, two of the three layers could be driven to provide weaker movements of the flexible membrane 10, insufficient to eject a droplet, but which can be tailored to generate pressure waves in the fluid chamber that cancel out reflected pressure waves in the fluid chamber or those arriving from adjacent fluid chambers (such undesirable pressure waves are referred to as fluidic cross-talk). Cross-talk can otherwise cause undesirable effects such as an unwanted droplet ejection events, or the release of smaller sub-droplets, or the release of a droplet of a larger or smaller volume than desired.

Turning now to Fig. 6A, this shows a top view of an electrical element 23 according to another embodiment, similar to that of Fig. 5A, but where the first group of electrodes G1(41) of the first electrode layer 41 and the first group of electrodes G1(43) of the third electrode layer 43 are electrically connected to each other, i.e. the common connector C1(41)

of G1(41) is electrically connected to the common connector C1(43) of G1(43) via a short 61 and where the second group of electrodes G2(41) of the first electrode layer 41 and the second group of electrodes G2(43) of the third electrode layer 43 are electrically connected to each other, i.e. the common connector C2(41) of G2(41) is electrically connected to the common connector C2(43) of G2(43) via the short 62. This arrangement (seen more clearly in Fig. 6F, for example) may reduce the complexity of the electrical connections to the electrical element 23 since only four traces and four electrical contacts OL,OR,IL,IR (as for the embodiment of Fig. 2A) are required, as opposed to the six electrical traces of the electrical element 22 of Fig. 5A. This may be advantageous where space on a die, or space in a device is of importance, or where close packing of multiple electrical elements is required.

In the following, Fig. 6B is a side view of the embodiment of Fig. 6A; Fig. 6C is a perspective view of the embodiment depicted in Fig. 6A; Fig. 6D is a cross-section through the embodiment depicted in Fig. 6A along the line AA; Fig. 6E is a cross-section through the embodiment depicted in Fig. 6A along the line BB; and Fig. 6F is a perspective view of the first, second and third layers of electrodes 41,42,43 and their electrical connections for the embodiment depicted in Fig. 6A (e.g. with all other features omitted).

It can be seen from both Fig. 5A and Fig. 6A that, in these embodiments, the third electrode layer 43 is disposed adjacent to the flexible membrane 10, the second electrode layer 42 is disposed adjacent to and between the first and second layers 31,32 of the ceramic member 30 and the first electrode layer 41 is disposed adjacent to the first layer 31 of the ceramic member 30. It may be understood that, as previously discussed with reference to Fig. 2, that the first layer 31 and the second layer 32 may comprise a single layer, but this is by no means limiting and the ceramic member 30 may comprise a plurality of layers 31(i-n) and (where present) 32(i-n). For example, the layer 31,32 may be formed by depositing a plurality of sub-layers, for example, by chemical vapour deposition (CVD), chemical solution deposition (CSD), sol-gel deposition, etc. so as to build up multiple layers to form a ceramic member 30 of a desired thickness.

Turning now to Figs. 7A,7B and 8A,8B, these depict an electrical element 24 similar to those of Figs. 3A-3B and 4A-4B, but comprising three electrode layers 41,42,43. For simplicity, the ceramic member 30 is depicted as a continuous component in Figs. 7A and

8A but it may be understood that it comprises two layers 31,32 as depicted in, for example Figs. 5C and 6C.

Fig. 7A depicts a cross-section through an electrical element 24 where the groups of electrodes G1(41),G2(41),G1(42),G2(42),G1(43),G2(43) have been shaded to show whether they have had a first voltage V1 or a second voltage V2 applied to them and whether the chosen groups and the voltages applied to them would lead to the ceramic member 30 deforming in d33 mode.

Fig. 7B represents the three electrode layers 41,42,43 of the electrical element 24 of Fig. 7A, again with the groups of electrodes G1(41),G2(41),G1(42),G2(42),G1(43),G2(43) and respective components electrically connected to them shaded to show whether they have had a first voltage V1 (grey) or a second voltage V2 (black) applied to them.

It can be seen that Figs. 7A-7B are similar to Figs. 3A-3B, where alternate columns 91,92 of electrode fingers in the interdigitation direction 81 are at a voltage V1 or a second voltage V2. As in Figs. 3A-3B, such an arrangement would create an effective potential field in the interdigitation direction 81 that would cause the ceramic member 30 to deform in d33 mode and bend UP. The effect would be the same whether the relevant voltages are applied through six electrical contacts OL,IL,OL2,OR,IR,OR2, acting as electrical inputs for an arrangement as in Figs. 5A-5E, or whether the voltages are applied through four electrical contacts OL,IL,OR,IR acting as electrical inputs as for the arrangement of Figs. 6A-6F.

For clarity, in Fig. 7B the arrangement of Figs. 6A-6F is indicated by dotted black lines for the short 61 connecting the first groups of electrodes G1(41),G1(43) and by dotted grey lines for the short 62 connecting the second groups of electrodes G2(41),G2(43) of the first and third electrode layers 41,43.

As for Fig. 7A, Fig. 8A depicts a cross-section through an electrical element 24 where the groups of electrodes are shaded to show whether they have had a first voltage V1 (grey) or a second voltage V2 (black) applied to them. It can be seen from Figs. 8A and 8B that in this implementation, the first and third electrode layers 41,43 are at a first voltage V1 and the second electrode layer 42 is at a second voltage V2. As for Fig. 4A and Fig. 4B, the potential difference established by this arrangement would be in the depth direction 80 and, where the second voltage V2 is greater than the first voltage V1, the applied voltages would lead to the ceramic member 30 deforming in d31 mode and moving DOWN in the depth direction 80. This movement could be achieved by applying appropriate voltages V1,V2 to

the six electrical contacts OL,IL,OL2,OR,IR,OR2 for an arrangement as in Figs. 5A-5E. The same effect could also be achieved by applying the appropriate voltages V1,V2 to the four electrical contacts OL,IL,OR,IR acting as electrical inputs for an arrangement as in Figs. 6A-6F, where the dotted grey lines indicate the short 61 and the short 62. As for Fig. 7B, the short 61 connects the first groups of electrodes G1(41),G1(43) and the short 62 connects the second groups of electrodes G2(41),G2(43) of the first and third electrode layers 41,43.

There are two main methods of applying the appropriate voltages to the chosen group or groups of electrodes using two or more drive voltages so as to deform the electrical element in a chosen sequence of d31 and/or d33 modes.

Switching circuit method and apparatus

The first such method comprises controlling a switching circuit so as to connect and disconnect the first drive signal and/or the second drive signal from the respective group electrical contacts in accordance with the chosen sequence. An arrangement comprising a switching circuit 85 is depicted in Figs. 9A and 9B. Fig. 9A depicts a switching arrangement for an electrical element such as that of Figs. 6A-6F. For simplicity, the ceramic layer 30 is omitted so only the electrode layers are shown and in each electrode layer 41,42,43 a single finger (i) for each group of electrodes G1,G2 is depicted (it can be imagined that the image is slightly tilted so as to show two adjacent fingers in each electrode layer 41,42,43), e.g. Fig. 9A is showing the same applied voltages as Fig. 7B, but only depicts a single finger in each electrode layer 41,42,43.

In the arrangement shown in Fig. 9A, the switch 71 connects the first group electrical contact OL to the third group electrical contact IL and both are supplied with a drive signal at a second voltage V2. The switch 72 connects the second and fourth group electrical contacts OR and IR to a drive signal at a first voltage V1. The result is that the first groups of electrodes G1(41),G1(42) and G1(43) are at a second voltage V2 and that the second groups of electrodes G2(41),G2(42) and G2(43) are at a first voltage V1. Where there is a difference in voltage between the first voltage V1 and the second voltage V2, the voltages applied and the positions of the switches 71,72, are such as to cause the ceramic member 30 to deflect in d33 mode.

Fig. 9B depicts a similar switching arrangement for an electrical element to that of Fig. 9A but where the positions of the switches 71,72 have changed. It can be seen that Fig.

9B depicts the same applied voltages as Fig. 8B, but only depicts a single finger in each electrode layer 41,42,43.

In the arrangement shown in Fig. 9B, the switch 71 connects the first group electrical contact OL to a drive signal at a first voltage V1. The third group electrical contact IL remains connected to a drive signal at a second voltage V2. The second group electrical contact OR remains connected to a drive signal at a first voltage V1 and the switch 72 has moved to connect the fourth group electrical contact IR to a drive signal at a second voltage V2. The result is that the first and second groups of electrodes G1(41),G1(43),G2(41),G2(43) in the first and third electrode layers 41,43 are at a first voltage V1 and that the first and second groups of electrodes G1(42),G2(42) in the second electrode layer 42 are at a second voltage V2. When there is a difference in voltage between V1 and V2 ($V2 > V1$), the voltages applied and the positions of the switches 71,72, are such as to cause the ceramic member 30 to deflect in d31 mode. To return the ceramic member 30 and the flexible membrane to a neutral position, the voltages V1 and V2 may be turned off so that there is no applied voltage and hence no potential difference applied to the ceramic member. Alternative methods, such as further switches to connect to a ground when desired may also be implemented.

Figs. 9A and 9B therefore depict a switching circuit 85 for an electrical element 21,22,23, 24 as described herein or a MEMS device, such as a droplet ejection apparatus, incorporating such an electrical element where the electrical element 21,22,23,24 is configured as an electrical actuator element and wherein the switching circuit 85 comprises at least two switches 71,72 so as to connect and/or disconnect at least two drive signals from chosen one of the group electrical contacts OL,IL,OR,IR [wherein said group electrical contacts are configured as electrical inputs] and whereby the switching circuit 85 enables the electrical element 21,22,23,24 to be deformed in a chosen sequence of d31 and/or d33 modes. When the switching circuit 85 is for a droplet ejection apparatus, it enables the electrical element to be deformed in a chosen sequence of d31 and/or d33 modes and thereby move the flexible membrane 10 and eject a droplet from the nozzle.

It may be understood that whilst the switching circuit 85 as depicted in Figs. 9A and 9B is for an electrical element such as that of Figs. 6A-6F, it may further be understood that with the omission of the shorts 61,62 and the third electrode layer 43 the switching circuit 85 would work equally well for an electrical element such as that of Fig. 2 which comprises

two electrode layers 41,42. Further, for an electrical element such as that of Figs. 5A-5E, where there are no shorts 61,62 connecting groups of electrodes in different layers, a similar arrangement to that of Figs. 9A-9B, but comprising further switches, could be used to apply the appropriate voltages to the additional group electrical inputs OL2 and OR2 whereby
5 there would be a switching circuit 85 comprising a plurality of switches.

Turning again to Figs. 9A and 9B, it can be seen that there is a controller 86 for the switching circuit 85 such that the controller 86 supplies a control signal to the switching circuit 85 so as to implement the chosen sequence of deformation modes. Such a controller 86 may be a pre-programmed controller 86 and may be arranged in close proximity to the
10 electrical element or elements so as to provide control signals to the switches 71,72. Further, the controller 86 may be mounted on the droplet ejection head.

Alternatively, the controller 86 may be supplied with the information from an external controller 87, as shown in Fig. 9B. The external controller may be part of the droplet ejection apparatus but may be located outside of the droplet ejection head. The controller
15 may be a separate control board or may be a part of the control circuitry of the droplet ejection apparatus that may be configured to control the functions of various components of the droplet ejection apparatus. The controller 86 may be a system-on-chip module, a computing device, a micro-processor, an application-specific integrated circuit (ASIC), or any other suitable device to control the switches 71,72. Furthermore, the controller 86 or the
20 external controller 87 may be configured to be controlled by an external processor. The external processor may comprise a user interface to adjust the printing process parameters, for example the external processor may be a personal computer, or any other suitable apparatus with a user interface.

It may further be understood that in some arrangements the shorts 61,62 connecting
25 the groups of electrodes of the first and third electrode layers 41,43 may also comprise switches such that the electrical element may be connected and driven in a 2-layer mode such as that depicted in Figs. 2A-2E, Figs. 3A-3B and Figs. 4A-4B or in a 3-layer mode such as that depicted in Figs. 6A-6F, Figs. 7A-7B and Figs. 8A-8B. Such changes in number of layers in operation may be controlled by the controller 86, or in response to an input
30 received from an external processor, for example if a user requires information on an actuator's status and operability and wishes to implement a testing program to determine this and to change the operating mode. It may further be understood that a switching circuit

may comprise switches such that any two of the three layers present in a 3-layer arrangement can be driven to deform the electrical element in a 2-layer mode. Such flexibility may be desirable, for instance, when the aim is to provide weaker deflections for testing or pressure pulse cancellation as previously discussed.

5

Drive signal method and drive signals

The second method of applying the appropriate voltages to the chosen group or groups of electrodes so as to deform the electrical element, where it may be understood that the electrical element is being used as an actuator, in a chosen sequence of d31 and/or d33
10 modes is a method that comprises supplying up to four drive signals DOL,DOR,DIL,DIR to the electrical element via the respective group electrical contacts OL,OR,IL,IR wherein the voltage in at least one of the four drive signals is varied so as to implement the chosen sequence. For example the method may comprise:

- supplying a first drive signal DOL to the first group of electrodes G1(41) in the first
15 electrode layer 41 [by addressing the first group electrical contact (OL)]; and
- supplying a second drive signal DOR to the second group of electrodes G2(41) in the first electrode layer 41 [by addressing the second group electrical contact (OR)]; and
- supplying a third drive signal DIL to the first group of electrodes G1(42) in the second electrode layer 42 [by addressing the third group electrical contact (IL)]; and
20
- supplying a fourth drive signal DIR to the second group of electrodes G2(42) in the second electrode layer 42 [by addressing the fourth group electrical contact (IR)].

Some non-limiting examples of such drive signals are depicted in Figs. 10A to 15E and described below. It may be understood that where there is a third electrode layer 43, an additional pair of drive signals may be used to drive the third layer. Alternatively, as shown
25 in Figs. 6A-6F, groups of electrodes in three layers may be suitably electronically connected so that only four drive signals are required.

As a general rule, what is required is a drive signal for an electrical actuator element; where the electrical actuator element comprises: a ceramic member 30 having a depth; where the ceramic member 30 comprises at least one layer 31 and first and second electrode layers
30 disposed adjacent the at least one layer 31 of the ceramic member 30, such that a potential difference may be established through at least a portion of the ceramic member 30 during operation. The electrical actuator element 20,21,22,23,24, is arranged adjacent to a flexible

membrane 10, and the first electrode layer 41 comprises a first group of electrodes G1(41) and a second group of electrodes G2(41) where one of the first and second groups of electrodes G1(41),G2(41) comprises at least one finger and the other of the first and second groups of electrodes G1(41),G2(41) comprises at least two fingers; and wherein the fingers of the first and second groups of electrodes G1(41),G2(41) are arranged alternately in the first electrode layer 41.

The second electrode layer 42 comprises a first group of electrodes G1(42) and a second group of electrodes G2(42), wherein one of the first and second groups of electrodes G1(42),G2(42) comprises at least one finger and the other of the first and second groups of electrodes G1(42),G2(42) comprises at least two fingers. The fingers of the first and second groups of electrodes G1(42),G2(42) are arranged alternately in the second electrode layer. For each group of electrodes G1(41),G2(41),G1(42),G2(42) all the fingers in said group are electrically connected to each other and to a group electrical input OL,OR,IL,IR; and wherein by choosing respective groups of electrodes to establish a potential difference between the respective groups, the ceramic member can be deformed in d31 mode or d33 mode; and wherein the drive signal comprises up to four drive signals DOL,DOR,DIL,DIR and whereby the drive signals are supplied to one of the group electrical contacts OL,OR,IL,IR and wherein the voltage in at least one of the four drive signals is varied so as to establish a potential difference between the respective groups of electrodes and thereby deform the ceramic member 30 in a chosen sequence of d31 and d33 modes and thereby move the flexible membrane 10. Using multiple drive waveforms in this manner, rather than a switching circuit, may be advantageous in terms of space used on the die, since the switching circuit and connections would no longer be required. It also allows for great design flexibility as depending on the application different combinations of drive signals can be used to create a desired effect and fine-tune the actuator performance.

Considering first Fig. 10A, this depicts a drive signal for an electrical actuator element comprising a first drive signal DOL (supplied to group electrical contact OL, and hence to the first group of electrodes G1(41) of the first electrode layer 41), a second drive signal DOR (supplied to group electrical contact OR, and hence to the second group of electrodes G2(41) of the first electrode layer 41), a third drive signal DIL (supplied to group electrical contact IL, and hence to the first group of electrodes G1(42) of the second electrode layer 42) and a fourth drive signal DIR (supplied to group electrical contact IR,

and hence to the second group of electrodes G2(42) of the second electrode layer 42). For clarity, the drive signals DOL,DOR,DIL and DIR are depicted shifted on the vertical axis in Fig. 10A, so that they can be distinguished from each other. In this example, the voltages of two of the drive signals DIL and DIR are varied over time such that they will cause a ceramic member 30 to deform in d31 mode, the other two drive signals are maintained at a constant voltage, for example, first voltage V1.

Fig. 10B depicts the displacement of the electrical element, (displacement is shown as a percentage of the total displacement achieved in response to the drive signal of Fig. 10A) and Fig. 10C depicts the applied voltages at the three stages M,N, and O of the drive signal when applied to an electrical element such as that of Figs. 6A-6F through the group electrical contacts OL,OR,IL,IR. Fig. 10C uses the same representational method as Fig. 9A and Fig. 9B where a single finger (i) of each group of electrodes in each electrode layer 41, 42, 43 is shown, and the shading indicates the applied voltage, first voltage V1 (grey) or second voltage V2 (black).

As previously discussed, where the flexible membrane 10 forms part of a fluid chamber and is to be driven in d31 mode so as to eject a droplet, it may be desirable to hold the ceramic member 30 deformed in d31 mode prior to an actuation event, so that the flexible membrane 10 deflects DOWN into the fluid chamber. This is shown in stage M of Fig. 10A and Fig. 10B, and in the schematic of Fig. 10C. As such the first drive signal DOL comprises a first holding signal HOL, the second drive signal DOR comprises a second holding signal HOR, the third drive signal DIL comprises a third holding signal HIL and the fourth drive signal DIR comprises a fourth holding signal HIR. The holding signals HOL,HOR,HIL,HIR have a duration d. The first and second holding signals HOL,HOR, are at a first voltage V1 and the third and the fourth holding signals HIL,HIR, are at a second voltage V2, where $V2 > V1$, so that when the drive signals DOL,DOR,DIL,DIR are supplied to the ceramic member 30 it is deformed in d31 mode, e.g. d31 ON for a duration d.

The chosen duration d may be to hold the ceramic member 30 deformed in d31 mode until an actuation event or other movement of the ceramic member 30 is required. Depending on the operational requirements, the duration d may be varied. It may be understood that where a number of actuation events follow each other in close succession, the duration d of the hold signal may be short, or it may be omitted, or a series of post-pulses after each firing event may be used as well/instead. It may further be understood that in some

implementations, the ceramic member 30 may instead be held in a neutral position prior to and/or between actuation events and instead a pre-pulse or a series of pre-pulses may be used to deform the ceramic member 30 in d31 mode prior to the actuation event.

It can be seen from Fig. 10A that a driving sequence for actuation in d31 mode may be as follows:

First stage M: the third and fourth drive signals DIL,DIR are at second voltage V2 and the first and second drive signals DOL and DOR are at a first voltage V1 where $V2 > V1$. These voltages are held for a length of time and it can be seen from Fig. 10B that consequently the ceramic member 30 is held in a d31 deformed (DOWN) position (first stage M at -100% displacement). Then:

Second stage N: at time $t=t1$, the third and fourth drive signals DIL,DIR switch to the first voltage V1 for a duration d1 such that all four drive signals DIL,DIR,DOL,DOR are at first voltage V1 and in response the ceramic member 30 moves to a neutral undeformed position at $t=t1$ (0% displacement, see Fig. 10B) for the duration d1;

Third stage O: then at $t=t1+d1$, the third and fourth drive signals DIL,DIR change back to the second voltage V2 and the electrical element returns to a d31 deformed DOWN position.

The effect of this driving sequence on the groups of electrodes is shown in Fig. 10C (first and third stage M,O) and Fig. 10D (second stage N).

To summarise, when driving the piezoelectric member in d31 mode so as to eject a droplet, starting from a d31 deformed mode position, the drive signal may change as follows at a start time $t=t1$: the third drive signal DIL and the fourth drive signal DIR simultaneously switch from the second voltage V2 to the first voltage V1 for a duration d1 and then the third drive signal DIL and the fourth drive signal DIR simultaneously revert to the second voltage V2, e.g. the ceramic member 30 experiences: d31 OFF, and moves to a neutral undeformed position for duration d1 and then d31 ON again.

Where the electrical element of Fig. 10 is an electrical actuator element for a droplet ejection apparatus, the flexible membrane may start deflection into the fluidic chamber in stage M, then move to a neutral position in stage N, increasing the chamber volume and drawing in fluid (DRAW), the return to a deflected position in stage O will then reduce the chamber volume and if the time duration d1 and the difference in voltage between V2 and

V1 is sufficient then a droplet of fluid will be ejected from the fluid chamber via the nozzle (PUSH).

Turning now to Fig. 11, this comprises a similar series of images to Fig. 10 for an electrical element acting as an electrical actuator element, but here the drive signal causes the ceramic member 30 to deform in d33 mode. Fig. 11A depicts the drive signal comprising first, second, third and fourth drive signals, DOL, DOR, DIL, DIR respectively. Fig. 11B depicts the percentage displacement of the electrical element in response to the drive signal of Fig. 11A. Fig. 11C and Fig. 11D depict the voltages as applied to an electrical element such as that of Figs. 6A-6F in response to the drive signal of Fig. 11A, using the same representational method as Fig. 9A and Fig. 9B where a single finger (i) of each group of electrodes in each electrode layer 41, 42, 43 is shown, and the shading indicates the applied voltage, first voltage V1 (grey) or second voltage V2 (black).

As can be seen from Fig. 11:

First stage M: the electrical element starts in a neutral position, with no potential difference across the ceramic member 30, e.g. the first, second, third, and fourth drive signals DOL, DOR, DIL, DIR are all at a first voltage V1. Subsequently:

Second stage N: at time $t=t_1$ the first drive signal DOL and the third drive signal DIL simultaneously switch from the first voltage V1 to the second voltage V2 (deforming the ceramic member in d33 mode) for a duration d_1 ;

Third stage O: then after a duration d_1 the first and third drive signals DOL, DIL, revert to the first voltage V1 (and the ceramic member 30 returns to a neutral position).

This is a deformation cycle that starts in a neutral position with d33 OFF, switches to d33 ON (DRAW) and then back to d33 OFF (PUSH) as can be seen from Fig. 11B. Where the electrical actuator element is being used for droplet ejection, this equates to a DRAW of fluid into the chamber as its volume increases with the ceramic member 30 deforming UP, and a PUSH of fluid out of the chamber as its volume decreases with the ceramic member 30 moving back DOWN to a neutral position, if the voltage difference between V1 and V2 and the duration d_1 is sufficient, this drive signal will cause a droplet ejection event.

It may be understood that where an electrical element is configured such that it can be driven in either d33 or d31 mode, then drive signals can be developed that use this capability to drive the ceramic member 30 in a combination of both deformation modes. There are a plurality of permutations that would be possible, the drive signals illustrated in

Figs. 12A to 15E and discussed below describe a limited series of drive signals that would cause the ceramic member 30 to move in a sequence of d31 and d33 deformations.

MODE 1:

Considering now Fig. 12, this comprises a similar series of figures to those of Figs. 10A-10D and Figs. 11A-11D, but where the ceramic member is deformed in a combination of d33 and d31 modes, referred to as MODE 1. As in previous figures, Fig. 12C depicts the voltages on a single finger in each group of electrodes in each electrode layer 41,42,43 in stage M (and P), similarly Fig. 12D depicts the voltages in stage N and Fig. 12E the voltages in stage O. Fig. 12A depicts the drive signals to achieve MODE 1 deformation:

First stage M: first, second, third and fourth drive signals DOL,DOR,DIL,DIR all start at a first voltage V1, it can also be seen from Fig. 12B that in first stage M, the voltage is V1 for all the fingers in all the groups of electrodes and the ceramic member will be in its neutral undeformed state. Subsequently:

Second stage N: at time $t=t_1$ the first drive signal DOL and the third drive signal DIL simultaneously switch from the first voltage V1 to the second voltage V2 (d33 ON) the voltages of all the fingers in one group of electrodes in each electrode layer 41,42,43 will be at first voltage V1 and all the fingers in the other group of electrodes in each electrode layer 41,42,43 will be at second voltage V2 and the ceramic member 30 will deform in d33 mode (it may be noted that it does not matter which group of electrodes is at first voltage V1 and which group of electrodes is at second voltage V2, as long as the same group of electrodes in each layer 41,42 is at the same voltage, e.g. so that the groups of electrodes alternate between first voltage V1 and second voltage V2, as illustrated in Fig. 7A, to form a series of columns 91(i),92(i),91(ii),92(ii), etc. where all the electrode fingers in the same column are at the same voltage);

Third stage O: then after a duration d2, the first drive signal DOL reverts to the first voltage V1 and simultaneously the fourth drive signal DIR switches from the first voltage V1 to the second voltage V2 (d33 OFF and d31 ON) the first and third electrode layers 41, 43 are at a first voltage V1 and the second electrode layer 42 is at a second voltage V2 whereby the ceramic member will deform in d31 mode; finally:

Fourth stage P: after a duration d3, the third drive signal DIL and the fourth drive signal DIR switch from the second voltage V2 to the first voltage V1 (d33 and d31 OFF)

and it can be seen from Fig. 12C that in stage P, as stage M, the voltage is V1 for all the fingers in all the groups of electrodes and the ceramic member 30 will be in its neutral undeformed state.

Using such a drive signal, the method for deforming a ceramic member 30 in MODE 1 comprises starting with the ceramic member 30 in a neutral position with d33 and d31 deformation modes OFF and then supplying four drive signals to the group electrical contacts so as to: switch d33 deformation mode ON for a duration d2 and then simultaneously switching d33 deformation mode OFF and d31 deformation mode ON for a subsequent duration d3 and then switching d31 deformation mode OFF and returning to a neutral position with d33 and d31 deformation modes both OFF.

MODE 2:

Considering Figs. 13A-13D, these comprise a similar series of figures to those of Fig. 10A to Fig. 12E, but where the ceramic member 30 is deformed in a combination of d33 and d31 modes, different to that of Figs. 12A-12E, referred to as MODE 2. Fig. 13C shows the voltages on a single finger (i) in each group of electrodes in each electrode layer 41,42,43 in stage M (and O) and Fig. 13D similarly shows the voltages in stage N. It can be seen from Fig. 13A that:

First stage M: the first and second drive signals DOL,DOR are at the first voltage V1 and the third and fourth drive signals, DIL,DIR are at the second voltage V2 such that the ceramic member 30 is deformed DOWN in d31 mode, as shown by the negative displacement in Fig. 13B; then:

Second stage N: at time $t=t_1$, the first drive signal DOL switches from the first voltage V1 to the second voltage V2 for a duration d1 and simultaneously the fourth drive signal DIR switches from the second voltage V2 to the first voltage V1 for a duration d1 (d31 OFF, d33 ON) the ceramic member 30 deforms UP in d33 mode, as seen in Fig. 13B;

Third stage O: at $t=t_1+d_1$ the first drive signal DOL reverts to the first voltage V1 and the fourth drive signal DIR reverts to the second voltage V2 (d33 OFF, d31 ON) the ceramic member 30 reverts to deformed DOWN in d31 mode.

Hence the method for deforming the ceramic member 30 in MODE 2 comprises starting with the ceramic member 30 deformed DOWN in d31 mode and then simultaneously switching d31 deformation OFF and switching d33 deformation ON for a

duration d1 and then simultaneously switching d33 deformation OFF and d31 deformation ON.

MODE 3:

5 Turning now to Figs. 14A-14E, these depict an arrangement where the ceramic member 30 is deformed in a combination of d33 and d31 modes referred to as MODE 3:

First stage M: it can be seen from Fig. 14A that as for MODE 1 the first, second, third and fourth drive signals DOL,DOR,DIL,DIR all start at a first voltage V1 and the ceramic member 30 is in a neutral position (see Fig 14B). Subsequently:

10 Second stage N: at $t=t_1$ the third drive signal DIL and the fourth drive signal DIR simultaneously switch from the first voltage V1 to the second voltage V2 for a duration d4 (D31 ON, D33 OFF);

Third stage O: after the duration d4 the fourth drive signal DIR switches from the second voltage V2 to the first voltage V1 and simultaneously the first drive signal DOL
15 switches from the first voltage V1 to the second voltage V2 (d31 OFF, d33 ON); subsequently:

Fourth stage P: after a duration d5, the first drive signal DOL switches from the second voltage V2 to the first voltage V1 and simultaneously the fourth drive signal DIR switches from the first voltage V1 to the second voltage V2 (d31 ON, d33 OFF); finally:

20 Fifth stage Q: after a duration d6, the third drive signal DIL and the fourth drive signal DIR simultaneously switch from the second voltage V2 to the first voltage V1 (d31 OFF, d33 OFF) and the ceramic member 30 returns to a neutral position.

Hence the method for deforming the ceramic member 30 in MODE 3 comprises starting with the ceramic member 30 in a neutral position and then switching d31 ON for a
25 duration d4 and then simultaneously switching d31 OFF and d33 ON for a duration d5 and then simultaneously switching d31 ON and d33 OFF for a duration d6 and then switching d31 OFF so that the ceramic member returns to a neutral position.

MODE 4:

30 Finally, considering Figs. 15A-15E, these depict MODE 4:

First stage M: as for MODE 2, MODE 4 commences with the first and second drive signals DOL,DOR at a first voltage V1 and the third and fourth drive signals DIL,DIR at a

second voltage V2 (for e.g. such that the ceramic member 30 is deformed DOWN in d31 mode) and then:

Second stage N: at $t=t_1$, the third drive signal DIL and the fourth drive signal DIR simultaneously switch from the second voltage V2 to the first voltage V1 for a duration d4
5 thereby switching d31 OFF such that the ceramic member 30 moves to a neutral position for the duration d4; then

Third stage O: at $t=t_1+d_4$, the first drive signal DOL and the third drive signal DIL simultaneously switch from the first voltage V1 to the second voltage V2 for a duration d5 (d33 ON, ceramic member 30 deformed UP); subsequently:

10 Fourth stage P: at $t=t_1+d_4+d_5$, the first drive signal DOL and the third drive signal DIL then revert to the first voltage V1, switching d33 OFF and returning to a neutral position for a duration d6; finally:

Fifth stage Q: at $t=t_1+d_4+d_5+d_6$, the third drive signal DIL and the fourth drive signal DIR simultaneously switch from the first voltage V1 to the second voltage V2 deform
15 the ceramic member 30 DOWN by switching d31 ON. As can be seen from Fig. 15A the third drive signal DIL and the fourth drive signal DIR simultaneously switch from the second voltage V2 to the first voltage V1 for a duration d4, subsequently after the duration d4, the first drive signal DOL and the third drive signal DIL simultaneously switch from the first voltage V1 to the second voltage V2 for a duration d5 and then revert to the first voltage V1,
20 subsequently after a duration d6 the third drive signal DIL and the fourth drive signal DIR simultaneously switch from the first voltage V1 to the second voltage V2.

It may be understood that the modes described herein are a small sub-selection of possible modes of operation and their associated methods and drive signals. They provide flexibility of design and operational performance by offering a suite of possible drive
25 waveforms. The skilled person may develop suitable drive signals and methods to deform the ceramic member in d31 and/or d33 mode and thereby use the electrical element as an electrical actuator element. Where it is required that the ceramic member 30, and hence the flexible membrane 10 start in a deformed position, then the drive signals DOL,DOR,DIL,DIR may comprise appropriate holding signals, HOL,HOR,HIL,HIR
30 respectively, at an appropriate combination of first and second voltages V1,V2 to deform the ceramic member 30 in d33 or d31 mode, as required.

Further, drive waveforms as described herein may additionally comprise pre-pulses and post-pulses, for example to address crosstalk or to provide additional fluidic priming and functionality, or to move the ceramic member 30 from one position to another position prior to an actuation event. A plurality of such drive waveforms may be strung together to form a sequence of deformation events and hence actuation events as required. It may be understood that suitable holding signals may be used between droplet ejection events to hold the ceramic member in the required position prior to the next deformation event in the sequence. It may be understood that any of the drive signals described herein may be supplied to a droplet ejection apparatus comprising at least one fluid chamber, the at least one fluid chamber comprising a fluid inlet, an electrical element and a nozzle for droplet ejection therefrom, and wherein the movement of the flexible membrane in response to an appropriate drive signal causes the ejection of a fluid droplet from the nozzle.

Sensor mode

As previously mentioned, the electrical element 20,21,22,23,24 as described herein may be operated as an electrical sensor element in idle times when not being used as an electrical actuator element. Alternatively, there may be an electrical element configured as an electrical sensor element and a MEMS device configured such that the electrical element is an electrical sensor element and where the group electrical contact or contacts are configured as an electrical output. In both cases there may be a method of sensing using an electrical sensor element, wherein said electrical sensor element comprises:

a) a ceramic member 30 wherein the ceramic member 30 comprises at least one ceramic layer 31 having a depth; and

b) first and second electrode layers 41,42, disposed adjacent the at least one ceramic layer 31 in the depth direction, such that a potential difference may be established through at least a portion of the ceramic layer 31 during operation.

The electrical sensor element 20,21,22,23,24 is arranged adjacent to a flexible membrane 10. The first electrode layer 41 comprises a first group of electrodes G1(41) and a second group of electrodes G2(41); wherein one of the first and second groups of electrodes G1(41),G2(41) comprises at least one finger and the other of the first and second groups of electrodes comprises at least two fingers; and where the fingers of the first and second groups of electrodes G1(41),G2(41) are arranged alternately in the first electrode

layer 41 in an interdigitation direction 81. The second electrode layer 42 comprises a first group of electrodes G1(42) and a second group of electrodes G2(42); wherein one of the first and second groups of electrodes G1(42),G2(42) comprises at least one finger and the other of the first and second groups of electrodes comprises at least two fingers; and wherein
5 the fingers of the first and second groups of electrodes G1(42),G2(42) are arranged alternately in the second electrode layer 42 in the interdigitation direction 81; and wherein for each group of electrodes G1(41),G2(41),G1(42),G2(42) all the fingers in the group are electrically connected to each other (through common connector) and to a group electrical contact OL,OR,IL,IR.

10 The first group of electrodes G1(41) of the first electrode layer 41 overlap in the interdigitation direction 81 with the first group of electrodes G1(42) of the second electrode layer 42; and the second group electrodes G2(41) of the first electrode layer 41 overlap in the interdigitation direction 81 with the second group of electrodes G2(42) of the second electrode layer 42. The ceramic member 30 can be deformed in d31 mode or d33 mode.

15 The method of sensing comprises the flexible membrane 10 moving in response to external force(s) and the ceramic member 30 thereby deforming in d31 and/or d33 modes so as to generate an electrical signal or signals which are supplied to one or more of the group electrical contacts OL,OR,IL,IR wherein the group electrical contacts OL,OR,IL,IR are configured as outputs. The method of sensing may further comprise measuring the
20 generated electrical signal or signals supplied to the one or more group electrical contacts OL,OR,IL,IR and using said signal or signals to determine the deformation of the flexible membrane 10 and hence determining the magnitude of the external force or forces. Such a method may, for example, comprise using pre-stored tables or lookup table(s) of known signals, known deformations and known forces to determine the force(s) applied to the
25 flexible membrane 10.

Alternative layouts

Figs. 16A-16D depict various alternative arrangements for the electrodes. Fig. 16A shows an arrangement with an electrical element 25 similar to that of Fig. 7A or Fig. 8A but
30 where one of the layers, in this case the second electrode layer 42, comprises fingers G1(42),G2(42) that are longer in the interdigitation direction 81 than those in the other two layers of electrodes 41,43, with the centre to centre spacing Z1 substantially the same so that

the groups of electrodes in the layers of electrodes 41,42,43 are aligned. It can be seen that consequently the gap y_2 between adjacent fingers in layer of electrodes 42 is therefore smaller than the gap y_1, y_3 in the other two layers. Such an arrangement may ensure that the fingers of the shorter electrodes in the two layers of electrodes 41,43 are contained within the length of the fingers $G1(42)(i-iii), G2(42)(i-iii)$ which are longer in the interdigitation direction 81 so as to ensure overlap, even if there is misalignment between layers. Such an arrangement may provide a more effective d31 deformation mode.

Turning now to Fig. 16B, this depicts an arrangement with an electrical element 26 with first and second electrode layers 41,42 and a third, continuous, electrode layer $G(42a)$ that is located between the first and second electrode layers 41 and 42, wherein only the first and second electrode layers 41,42 are interdigitated and where the first group of electrodes $G1(41)$ of the first electrode layer 41 and the first group of electrodes $G1(42)$ of the second electrode layer 42 may be electrically connected to each other and share a common group electrical connector and likewise where the second groups of electrodes $G2(41)$ and $G2(42)$ may be electrically connected to each other and share a common group electrical connector, whilst the third electrode layer $G(42a)$ has a separate group electrical input. As can further be seen from Fig. 16B, in this embodiment, the third electrode layer is closer to the flexible membrane than the first electrode layer, but the second electrode layer is closer to the flexible membrane than the third electrode layer. Such an arrangement may use the first and second electrode layers 41,42 for deformation in d33 mode, such that the alternate columns 91,92 of electrode fingers in the interdigitation direction 81 are formed from the first groups $G1(41), G1(42)$ and second groups $G2(41), G2(42)$ respectively of the first and second electrode layers 41,42, whilst leaving the third electrode layer $G(42a)$ neutral, for example. Such an arrangement may use all three layers for deformation in d31 mode in a similar manner to that shown in, for example, Fig. 8A.

Fig. 16C and Fig. 16D depict a top view of electrical elements 27 and 28 with the interdigitated fingers of the first electrode layer arranged in different orientations relative to the flexible membrane below (not shown) and hence (in the case of an electrical actuator element) to the fluid chamber, such that the interdigitation direction 81 is different in each case. In Fig. 16C, the interdigitation direction 81 is parallel to the chamber length direction y and in Fig. 16D the interdigitation direction 81 is perpendicular to the chamber length direction y . It may be understood that either orientation is suitable for use with any of the

embodiments and arrangements described herein and that in each case the second and (where present) third electrode layers 42,43 (not shown) may be oriented in the same way as the first electrode layer 41 so as to overlap appropriately.

5 Examples from Modelling Work

Modelling work was undertaken in COMSOL Multiphysics simulation software to investigate the effects of various configurations, the results are shown in below Tables 1-3. In Table 1 the applied voltage, electrical field, displacement and displaced area are shown and compared with a conventional d31 design (such as that of Fig. 1) where there are two continuous electrodes one on either side of the ceramic member.

Design	Mode	Voltage (V)	Field (V/ μm)	Displacement (m)	Displaced area (m^2)
8a	d33, 2.5- 2.5 μm (2 layers of electrodes)	25	10	1.21E-07	3.90E-12
8	d33, 2.5-2.5 μm (3 layers of electrodes)	25	10	1.35E-07	4.33E-12
8b	d33, 1- 4 μm (3 layers of electrodes)	40	10	2.34E-07	7.56E-12
8b	d33, 1- 4 μm (3 layers of electrodes)	20	5	1.17E-07	3.78E-12
8	d33, 2.5-2.5 μm (3 layers of electrodes)	20	8	1.077E-07	3.465E-12
7	d31(layer 41:10V-layer 42 0V-layer 43-10V)	10	10	1.39E-07	4.63E-12
7	d31	20	20	2.783E-07	8.63E-12
7a	d31, 2.5- 2.5 μm (layer 41 20V-layer 42 10V- layer 43 0V)	20 & 10	10	1.39E-07	4.63E-12
	d31 (conventional)	20	10	2.23E-07	7.47E-12
8+7 at 20V	d33 & d31, 2.5-2.5 μm (3 layers of electrodes)	20	8-20	3.86E-07	12.7E-12

Table 1. Various configurations

Table 2 depicts the effect of varying the width in the interdigitation direction 81 of the electrode fingers in the three layers of electrodes 41,42,43. The width is varied between 1 μm and 2.5 μm whilst keeping a constant pitch (centre-to-centre spacing Z1) of 5 μm and varying the applied voltage between 10 to 40V so as to give the same applied electric field of 10V/ μm in all cases. In this Table all the cases comprise 3 layers of electrodes 41,42,43, and the widths of the electrode fingers in the first and third layers 41,43 are the same.

Operation Mode	Contact width (μm) (41 and 43)	Contact width (μm) (42)	Voltage (V)	Displacement (m)	Displaced area (m^2)
d31	1	1	10	7.44E-08	2.47E-12
d31	2	2	10	1.12E-07	3.73E-12
d31	2.5	2.5	10	1.39E-07	4.63E-12
d31	1	2.5	10	9.91E-08	3.28E-12
d33	1	1	40	2.34E-07	7.56E-12
d33	2	2	30	1.59E-07	5.13E-12
d33	2.5	2.5	25	1.35E-07	4.33E-12
d33	1	2.5	40	2.52E-07	8.14E-12
d31 (conventional)	continuous		20	2.23E-07	7.47E-12
d31 (MLA)	continuous		10	1.99E-07	6.66E-12

Table 2. constant field 10V/ μm

The total displacement and total displaced area for different electrode widths in the case of d33 and d31 mode of operation are depicted. In all cases the same voltage difference of 20V was applied.

Operation Mode	Contact width (μm) (top and bottom)	Contact width (μm) (middle)	Voltage (V)	Displacement (m)	Displaced area (m^2)
d33 & d31 combined	1	1	20	2.66E-07	8.71E-12
d33 & d31 combined	2	2	20	3.30E-07	1.09E-11
d33 & d31 combined	2.5	2.5	20	3.86E-07	1.27E-11
d33 & d31 combined	1	2.5	20	3.24E-07	1.06E-11

Table 3. d33 and d31 combined displacements, constant voltage 20V

In the above tables the pitch between electrode fingers in each layer of electrodes is $5\mu\text{m}$ for all cases.

5

General considerations

Any of the electrical elements 20,21,22,23,24,25,26 described herein, or any of the variants of these embodiments could be incorporated into a MEMS device. In some MEMS devices, the electrical elements could be used as electrical actuator elements as described, for example in a droplet ejection apparatus where the droplet ejection apparatus comprises at least one fluid chamber, and where the fluid chamber comprises a fluid inlet and a nozzle for droplet ejection therefrom and at least one of the electrical elements 20,21,22,23,24, 25,26 described herein. Droplet ejection apparatus may be used for a variety of applications, including as a printing device. In such applications, the droplet ejection apparatus may comprise a plurality of such fluid chambers, which may be arranged in an array so as to address a large area of substrate. Some droplet ejection apparatus may comprise a plurality of droplet ejection heads, each of which comprises a plurality of such fluid chambers.

It may be understood that the number of fingers in each group of electrodes is not limited to those depicted herein, and that the minimum requirement is that one of the first and second groups of electrodes comprises at least one finger and that the other of the first and second groups of electrodes comprises at least two fingers. It may be further understood

20

that there may be an electrical element 20,21,22,23,24,25,26 according to any of the embodiments described herein wherein the groups of electrodes each comprise a plurality of fingers.

It may further be understood that there is no requirement for an even or odd number of fingers in any of the groups of electrodes; and further that provided the fingers in the first and second groups of electrodes in the electrode layer are arranged alternately, the first and second groups of electrodes may comprise the same number of fingers, or different numbers of fingers. In some embodiments, the number of fingers in the aligned groups may be the same, e.g. G1(41),G1(42),G1(43) have same number of fingers as each other and likewise G2(41),G2(42),G2(43) have the same number of fingers as each other.

It may further be understood that whilst the electrical element 20,21,22,23,24,25,26 is described as being disposed adjacent to and fixedly connected to the flexible membrane 10, it may not be directly connected to the flexible membrane 10 as other layer(s) may intervene, as required, between the parts of the electrical element 20,21,22,23,24,25,26 etc. and the flexible membrane 10. It may be understood that such layer(s) may comprise electrical and/or chemical passivation layer(s), adhesion layer(s), stress gradient mitigating layers, diffusion barriers, or any other additional layers that may be required for the construction and operation of the electrical element and that lie between the electrical element and the flexible membrane 10, similar to those described with reference to Fig. 1A and Fig. 1B. For example, where the electrode layers are made from platinum (Pt), a layer of zirconium dioxide (ZrO_2) between the flexible membrane 10 and the electrode layer adjacent to it (42 or 43 depending on the embodiment) may aid the growth of a ceramic such as PZT in areas where the platinum electrode was etched.

However, it may be understood that whether or not there are intervening layers between the electrical element 20,21,22,23,24,25,26 and the flexible membrane 10, the two are fixedly connected to each other such that when the electrical element 20,21,22,23,24,25,26 acts as an electrical actuator element and the ceramic member 30 is driven to deform in d33 and/or d31 mode it thereby moves the flexible membrane 10. Likewise, when the electrical element 20,21,22,23,24,25,26 is configured as or acting as a sensor it moves in response to forces applied to the flexible membrane and thereby the ceramic member 30 deforms in d33 and/or d31 mode and generates an electrical signal. Adjacent to and fixedly connected to may therefore be understood to encompass

arrangements where the electrical element 20,21,22,23,24,25,26 and flexible membrane 10 have intervening layers as described herein, whilst still allowing movement (e.g. deformation) of the electrical element 20,21,22,23,24,25,26 to cause movement of the flexible membrane 10 (and vice versa for an electrical sensor element).

5 It may further be understood that whilst the layer 31 and the layer 32 (where present) in the ceramic member are each depicted as a single layer, this is done for simplicity and the layers 31,32 may comprise a plurality of layers or sub-layers (e.g. a stack of layers 31(1-m) and 32(1-n)). For example such a stack of layers is typically formed from sequential depositions, e.g. depositing one thin film layer after another (e.g. 1, 2, 3- m/n) until the
10 desired thickness of the layer 31 and (where present) the layer 32 has been reached. Preparation of ceramic thin film layers for MEMS applications typically involves chemical solution deposition using chemical solution precursors, or sputtering (e.g. RF magnetron sputtering) using solid state sintered or hot-pressed ceramic targets. Any other suitable method of preparation may also be used.

15 The layers 31,32 may preferably be formed through chemical solution deposition. For example, a multi-layer thin film ceramic member 30 may be formed by means of multiple rounds of deposition and drying of precursor solution for the ceramic material, with crystallisation between each set of deposition and drying steps, or with a crystallisation step at the end of multiple rounds of deposition and drying. As will be appreciated, the
20 composition of each of the layers of a multi-layer thin film ceramic member 30 may be substantially identical. Alternatively, the composition of individual layers of a multi-layer thin film ceramic member 30 may be optimised to meet particular operational requirements, e.g. depending on whether, for instance, one of the sub-layers will be in contact with the substrate and/or an electrode of the electrical element. Thus, in such embodiments, the
25 composition of individual layers of a multi-layer thin film ceramic material 31(1-m),32(1-n) may be different to each other, e.g. they may comprise different dopants, different overall compositions, etc. Such flexibility of design may allow fine-tuning of the properties and hence performance of the ceramic member 30. It may further be understood that whilst the two layers 31,32 are depicted herein as being of the same thickness in the depth direction 80
30 this is by no means essential and the layers 31,32 may have different thicknesses and may comprise different numbers of sub-layers. Typical thicknesses of the ceramic member 30 in the depth direction 80 may be in the region of 0.5-3 μ m, or may be 1-2 μ m, typical examples

may be 1.3 μm , 1.4 μm , or 1.5 μm . The thickness of the ceramic member 30 depends on desired operating frequencies, generally higher operating frequencies may require thicker flexible membranes 10 and hence thicker ceramic members 30 to be more powerful so as to be able to drive the thicker flexible membrane (designing ceramic members with higher piezo efficiency may also be utilised). It may further be understood that, as appropriate based on respective locations, the layer(s) 31,32 may comprise portions that form the gap y_1, y_2, y_3 between adjacent fingers in the respective layer(s) of electrodes adjacent to them.

The groups of electrodes 41,42,43 may be between 100-200nm, for example of the order of 150nm thick in the depth direction 80. The thickness of the groups of electrodes 41,42, (and, where present) 43 may be the same or different, and they may comprise the same materials, or they may all comprise different materials, of the group of electrodes 42 contained in the ceramic member 30 may be a different material to those on its outer edges 41,43 in a 3-layer device. The materials and thicknesses of the groups of electrodes may be optimised for the design and purpose of the ceramic member 30. The groups of electrodes 41,42,43 may be formed by any suitable method, for example any suitable deposition technique, such as sputtering.

As will be appreciated by the skilled person, where there is a plurality of electrical elements, the ceramic member 30 may initially be deposited before being patterned and segmented, for instance by etching, into multiple separated ceramic members 30, each associated with an individual one of the plurality of electrical elements 20,21,22,23,24,25,26. It may further be understood that, whilst not depicted herein, additional layers, such as passivation layers and the like may overlie the electrical element to protect it from external damage, to provide electrical and chemical passivation and so on.

It may be understood that as used herein “ceramic material” encompasses any suitable material that exhibits ferroelectric behaviour, for example a piezoelectric material or a relaxor/ferroelectric crossover material. As described above, examples of suitable ceramic materials include, but are not limited to, lead based ceramics with perovskite structure, such as lead titanate zirconate (PZT), doped PZT and PZT based solid solutions. Other suitable ceramic materials include lead-free alternative ceramic materials such as (K,Na)NbO₃-based materials, (Ba,Ca)(Zr,Ti)O₃-based materials and (Bi,Na,K)TiO₃-based materials. These example materials are by no means limiting and other suitable materials may also be used.

It may be understood that where the first voltage V1 is a reference voltage, this voltage may be ground, but this is by no means essential, and the reference voltage may be a voltage other than ground.

It may further be understood that the first and second voltages V1, V2 as described herein are not limited and different voltages may be used. Furthermore, where the second voltage V2 is greater than the first voltage V1, the difference (V2-V1) between the first and second voltages V1, V2 is not limited. For example, smaller voltage differences may be used to provide smaller deflections, or greater voltage differences may be used with more viscous fluids or to provide greater deflections. Furthermore, different voltages or sequences of voltages or different voltage differences may be used to form the pre-pulses and post-pulses for crosstalk suppression and the like.

Still further, within a given drive waveform, different steps and levels of voltages may be used, rather than the binary first voltage V1, second voltage V2 used for the examples herein, e.g. second voltage V2 may comprise a range of second voltages V2 of varying voltage levels, with lower voltages used, for example, for pre-pulses and post-pulses, or for actuator sensing, or for actuator evaluation, and stronger voltages used when a droplet ejection event is required. Still further the lengths of the pulses (e.g. the durations of the changes from one deformation mode to another, or to/from a neutral position, may be varied as required. For example, a shorter duration pulse with low voltage may be used to move the actuator and excite the membrane, e.g. for sensing or testing actuator performance, whilst preventing droplet ejection. A long duration pulse, where the voltage changes slowly and gradually may likewise be used to move the ceramic member from one position to another (e.g. to a holding position) without causing a droplet ejection event.

It may be further understood that although the switching of voltage levels in Figs. 10A-15A are depicted as occurring instantaneously, however, it is by no means limited, and there could be slow rise and/or slow fall when switching from one voltage level to another. Also, there could be a delay while switching from one voltage level to another such delay could be predetermined or dynamic. Further, the difference between the voltage levels and the width of the pulses may be controlled as required. Consequently, according to the delay, maximum voltage, minimum voltage and/or pulse width, the changes in position of the ceramic member 30 (through steps M to P) depicted in Figs. 10B-15B may likewise be controlled.

It should be noted that the waveforms shown in Figs. 10A-15A are for ease of understanding and are not limited to a particular shape of waveform and they may take other forms and shapes for example, trapezoidal, sinusoidal etc. It may further be understood that although the waveforms involving both d31 deflection and d33 deflection are depicted as symmetrical, with the displacement split 50%:50% this is for ease of representation and asymmetric deformation to either side of the neutral position is possible. Further, for some applications asymmetry may be designed in so as to tune the deflection of the flexible membrane for a particular application. This may be done by designing a ceramic member whose d33 and d31 responses are asymmetric, and/or by use of asymmetric waveforms.

CLAIMS

1. An electrical element comprising:

a ceramic member, wherein said ceramic member comprises at least one layer having
5 a depth; and

first and second electrode layers disposed adjacent the at least one layer of the ceramic member, such that a potential difference may be established through at least a portion of the ceramic member during operation;

wherein said electrical element is arranged adjacent to a flexible membrane, and

10 wherein the first electrode layer comprises a first group of electrodes comprising at least two fingers and a second group of electrodes comprising at least one finger;

wherein the fingers of the first and second groups of electrodes are arranged alternately in the first electrode layer in an interdigitation direction; and

wherein the second electrode layer comprises a first group of electrodes comprising
15 at least two fingers and a second group of electrodes comprising at least one finger;

wherein the fingers of the first and second groups of electrodes are arranged alternately in the second electrode layer in an interdigitation direction; and

wherein for each group of electrodes all the fingers in said group are electrically connected to each other and to a group electrical contact; and

20 wherein the fingers of the first group of electrodes of the first electrode layer at least partially overlap in the interdigitation direction with the corresponding fingers of the first group of electrodes of the second electrode layer; and

wherein the fingers of the second group of electrodes of the first electrode layer at least partially overlap in the interdigitation direction with the corresponding fingers of the
25 second group of electrodes of the second electrode layer; and

wherein the group electrical contacts are arranged to be addressable to establish a potential difference between the fingers of the first and second groups of electrodes of the same electrode layer in the interdigitation direction and deformation of the ceramic member in d33 mode, and to be addressable to establish a potential difference in the depth direction
30 between said at least partially overlapping fingers of the first and second groups of electrodes of the first and second electrode layers and deformation of the ceramic member in d31 mode.

2. The electrical element according to claim 1, wherein said ceramic member further comprises at least a second ceramic layer having a depth and wherein said electrical element further comprises a third electrode layer.

3. The electrical element according to claim 2, wherein the third electrode layer comprises a first group of electrodes and a second group of electrodes wherein one of the groups of electrodes comprises at least one finger and wherein the other of the groups of electrodes comprises at least two fingers; and wherein the fingers of the first and second groups of electrodes are arranged alternately in the third electrode layer in the interdigitation direction; and

wherein for each group of electrodes all the fingers in said group are electrically connected to each other and to a group electrical contact.

4. The electrical element according to claim 2 or claim 3, wherein the third electrode layer is disposed adjacent to the flexible membrane, the second electrode layer is disposed adjacent to and between the first and second layers of the ceramic member and the first electrode layer is disposed adjacent to the first layer of the ceramic member.

5. The electrical element according to claim 2, wherein the third electrode layer is located between the first and second ceramic layers and said first and second electrode layers and wherein said third electrode layer is continuous.

6. The electrical element according to any of claims 2 to 5, wherein the first group of one electrode layer and the first group of another electrode layer are electrically connected to each other and share a common group electrical input and wherein the second group of one electrode layer and the second group of another electrode layer are electrically connected to each other and share a common group electrical input, such that a potential difference may be established in the interdigitation direction of at least a portion of the ceramic member during operation.

7. The electrical element according to any of claims 2 to 6, wherein the first group of one electrode layer and the second group of the same electrode layer are electrically

connected to each other and share a common group electrical input and wherein the first group of another electrode layer and the second group of the another electrode layer are electrically connected to each other and share a common group electrical input, such that a potential difference may be established in the depth direction of at least a portion of the ceramic member during operation.

8. A droplet ejection apparatus comprising at least one fluid chamber, the at least one fluid chamber comprising a fluid inlet and a nozzle for droplet ejection therefrom and at least one electrical element according to any of claims 1 to 7.

9. A MEMS device comprising an electrical element according to any of claims 1 to 7.

10. The MEMS device according to claim 9, configured such that the electrical element is an electrical sensor element,

wherein deformation of the ceramic member in d33 mode establishes a potential difference between the fingers of the first and second groups of electrodes of the same electrode layer creating an effective potential field aligned with the interdigitation direction, and

wherein deformation of the ceramic member in d31 mode establishes a potential difference between said at least partially overlapping fingers of the first and second groups of electrodes of the first and second electrode layers creating an effective potential field aligned with the depth direction.

11. The MEMS device according to claim 9, configured such that the electrical element is an electrical actuator element,

wherein the establishment of a potential difference between the fingers of the first and second groups of electrodes of the same electrode layer creating an effective potential field aligned with the interdigitation direction causes deformation of the ceramic member in d33 mode, and

wherein establishment of a potential difference between said at least partially overlapping fingers of the first and second groups of electrodes of the first and second

electrode layers creating an effective potential field aligned with the depth direction causes deformation in d31 mode.

12. A switching circuit for an electrical element according to any of claims 1 to 7 or a droplet ejection apparatus according to claim 8 or a MEMS device according to claim 9 or claim 11, wherein the switching circuit comprises at least two switches so as to connect and disconnect at least two drive signals from chosen ones of the group electrical contacts so as to deform the electrical element in a chosen sequence of d31 and d33 modes.

13. A controller for a switching circuit according to claim 12, wherein the controller supplies a control signal to the switching circuit so as to implement the chosen sequence of d31 and d33 modes.

14. A drive signal for an electrical actuator element, wherein said electrical actuator element comprises:

a ceramic member having a depth, wherein said ceramic member comprises at least one layer; and

first and second electrode layers disposed adjacent the at least one layer of the ceramic member, such that a potential difference may be established through at least a portion of the ceramic member during operation;

wherein said electrical actuator element is arranged adjacent to a flexible membrane, and

wherein the first electrode layer comprises a first group of electrodes and a second group of electrodes wherein one of the first and second groups of electrodes comprises at least one finger and the other of the first and second groups of electrodes comprises at least two fingers;

wherein the fingers of the first and second groups of electrodes are arranged alternately in the first electrode layer in an interdigitation direction; and

wherein the second electrode layer comprises a first group of electrodes and a second group of electrodes;

wherein one of the first and second groups of electrodes comprises at least one finger and the other of the first and second groups of electrodes comprises at least two fingers;

wherein the fingers of the first and second group of electrodes are arranged alternately in the second electrode layer in the interdigitation direction; and

wherein for each group of electrodes all the fingers in said group are electrically connected to each other and to a group electrical input;

5 wherein the fingers of the first group of electrodes of the first electrode layer at least partially overlap in the interdigitation direction with the corresponding fingers of the first group of electrodes of the second electrode layer; and

wherein the fingers of the second group of electrodes of the first electrode layer at least partially overlap in the interdigitation direction with the corresponding fingers of the
10 second group of electrodes of the second electrode layer; and

wherein by choosing respective groups of electrodes to establish a potential difference between the respective groups the ceramic member can be deformed in d31 mode and/or d33 mode; and

wherein the drive signal comprises at least four drive signals and whereby each drive
15 signal is supplied to one of the group electrical contacts and wherein the voltage in at least one of the at least four drive signals is varied so as to establish a potential difference between the respective groups of electrodes and thereby deform the ceramic member in a chosen sequence of d31 and/or d33 modes and thereby deform the electrical actuator element and move the flexible membrane.

20

15. The drive signal according to claim 14, wherein the drive signal comprises a first drive signal, a second drive signal, a third drive signal and a fourth drive signal.

16. The drive signal according to claim 15, wherein the first drive signal comprises a
25 first holding signal, the second drive signal comprises a second holding signal, the third drive signal comprises a third holding signal and the fourth drive signal comprises a fourth holding signal wherein said holding signals have a duration d.

17. The drive signal according to claim 16, wherein the first holding signal and the
30 second holding signal are at a first voltage and the third holding signal and the fourth holding signal are at a second voltage so as to deform the ceramic member in d31 mode and hold it there for the duration d.

18. The drive signal according to claim 16, wherein the first holding signal, the second holding signal, the third holding signal and the fourth holding signal are at a first voltage so as to hold the ceramic member undeformed for the duration d.

5

19. The drive signal according to claim 16, wherein the first holding signal, and the third holding signal are at a second voltage, and the second holding signal and the fourth holding signal are at a first voltage so as to deform the ceramic member in d33 mode and hold it there for the duration d.

10

20. The drive signal according to any of claims 15 to 19, wherein initially the first drive signal and the second drive signal are at a first voltage and the third drive signal and the fourth drive signal are at a second voltage; and

wherein simultaneously the third drive signal and the fourth drive signal switch from the second voltage to the first voltage for a duration d1; and

wherein after the duration d1 the third drive signal and the fourth drive signal simultaneously switch from the first voltage to the second voltage.

21. The drive signal according to any of claims 15 to 20, wherein initially the first drive signal, the second drive signal, the third drive signal and the fourth drive signal are at a first voltage; and

wherein the first drive signal and the third drive signal simultaneously switch from the first voltage to the second voltage for a duration d1; and

wherein after the duration d1 the first drive signal and the third drive signal simultaneously switch from the second voltage to the first voltage.

22. The drive signal according to any of claims 15 to 21, wherein initially the first drive signal, the second drive signal, the third drive signal and the fourth drive signal are at a first voltage; and

wherein the first drive signal and the third drive signal simultaneously switch from the first voltage to the second voltage; and

wherein after a duration d2 the first drive signal reverts to the first voltage and simultaneously the fourth drive signal switches from the first voltage to the second voltage; and

5 wherein after a subsequent duration d3 the third drive signal and the fourth drive signal switch from the second voltage to the first voltage.

23. The drive signal according to any of claims 15 to 22, wherein initially the first drive signal and the second drive signal are at a first voltage and the third drive signal and the fourth drive signal are at a second voltage; and

10 wherein simultaneously the first drive signal switches from the first voltage to the second voltage and the fourth drive signal switches from the second voltage to the first voltage for a duration d1; and

wherein after the duration d1 the first drive signal switches to the first voltage and the fourth drive signal switches to the second voltage.

15

24. The drive signal according to any of claims 15 to 23, wherein initially the first drive signal, the second drive signal, the third drive signal and the fourth drive signal are at a first voltage; and

20 wherein the third drive signal and the fourth drive signal simultaneously switch from the first voltage to the second voltage for a duration d4; and

wherein subsequently the first drive signal switches from the first voltage to the second voltage and simultaneously the fourth drive signal switches from the second voltage to the first voltage for a duration d5; and

25 wherein subsequently after the duration d5 the first drive signal switches from the second voltage to the first voltage and simultaneously the fourth drive signal switches from the first voltage to the second voltage for a duration d6; and

wherein after the duration d6 the third drive signal and the fourth drive signal simultaneously switch from the second voltage to the first voltage.

30 25. The drive signal according to any of claims 15 to 24, wherein initially the first drive signal and the second drive signal are at a first voltage and the third drive signal and the fourth drive signal are at a second voltage; and

wherein the third drive signal and the fourth drive signal simultaneously switch from the second voltage to the first voltage for a duration d4; and

wherein subsequently after the duration d4 the first drive signal and the third drive signal simultaneously switch from the first voltage to the second voltage for a duration d5;

5 and

wherein subsequently after the duration d5 the first drive signal and the third drive signal simultaneously switch from the second voltage to the first voltage for a duration d6; and

10 wherein subsequently after a duration d6 the third drive signal and the fourth drive signal simultaneously switch from the first voltage to the second voltage.

26. The drive signal according to any of claims 15 to 25, wherein the first voltage is a reference voltage.

15 27. The drive signal according to any of claims 15 to 26, wherein the second voltage is greater than the first voltage.

28. A method of driving an electrical actuator element, wherein said electrical actuator element comprises:

20 a ceramic member, wherein said ceramic member comprises at least one ceramic layer having a depth; and

first and second electrode layers disposed adjacent the at least one ceramic layer in the depth direction, such that a potential difference may be established through at least a portion of the ceramic member during operation;

25 wherein said electrical actuator element is arranged adjacent to a flexible membrane, and

wherein the first electrode layer comprises a first group of electrodes and a second group of electrodes;

30 wherein the fingers of the first and second groups of electrodes are arranged alternately in the first electrode layer in an interdigitation direction; and

wherein the second electrode layer comprises a first group of electrodes and a second group of electrodes; and

wherein the fingers of the first and second groups of electrodes are arranged alternately in the second electrode layer; and

wherein for each group of electrodes in the first and second electrode layers all the fingers in said group are electrically connected to each other and to a group electrical contact;
5 and

wherein the first group of electrodes of the first electrode layer at least partially overlap in the interdigitation direction with the first group of electrodes of the second electrode layer; and

wherein the second group electrodes of the first electrode layer at least partially
10 overlap in the interdigitation direction with the second group of electrodes of the second electrode layer; and

wherein the electrical actuator element is deformed by addressing chosen respective groups of electrodes and establishing a potential difference through at least a portion of the ceramic member and thereby deforming the ceramic member in d31 mode or d33 mode; and

15 wherein the method comprises:

- choosing the d31 deformation mode or the d33 deformation mode or choosing a sequence of d31 and/or d33 deformation modes; and

- supplying at least two drive signals to the electrical actuator element by addressing the respective group electrical contacts of chosen respective groups of electrodes thereby
20 establishing a potential difference between the chosen respective groups of electrodes and thereby deforming the ceramic member in the chosen deformation mode or the chosen sequence of deformation modes and thereby moving the flexible membrane.

29. The method according to claim 28, wherein deforming the ceramic member in d31
25 mode comprises the at least two drive signals establishing a potential difference between the chosen respective groups of electrodes by:

- providing a first voltage to the first group of electrodes in the first electrode layer and to the second group of electrodes in the first electrode layer; and

- providing a second voltage to the first group of electrodes in the second electrode
30 layer and to the second group of electrodes in the second electrode layer.

30. The method according to claim 28 or claim 29, wherein the method of deforming the ceramic member in d33 mode comprises the at least two drive signals establishing a potential difference between the chosen respective groups of electrodes by:

- providing a first voltage to the first group of electrodes in the first electrode layer and to the first group of electrodes in the second electrode layer; and
- providing a second voltage to the second group of electrodes in the first electrode layer and to the second group of electrodes in the second electrode layer.

31. The method according to any of claims 28 to 30, wherein the ceramic member comprises a neutral state wherein no potential difference is established across the ceramic member; and

wherein the method further comprises a step of holding the ceramic member in a neutral state prior to and/or after deforming the ceramic member in the chosen deformation mode or the chosen sequence of d31 and/or d33 deformation modes and/or as an intermediate step in the chosen sequence of d31 and/or d33 deformation modes.

32. The method according to any of claims 28 to 31, wherein the method further comprises a step of holding the ceramic member in a deformed state prior to and/or after deforming the ceramic member in the chosen deformation mode or the chosen sequence of d31 and/or d33 deformation modes and/or as an intermediate step in the chosen sequence of d31 and/or d33 deformation modes; and

wherein the method further comprises choosing whether to deform and hold in d33 mode or deform and hold in d31 mode.

33. The method according to any of claims 28 to 32, wherein the second voltage is greater than the first voltage.

34. The method according to any of claims 28 to 33, wherein the method further comprises supplying at least four drive signals to the electrical actuator element by addressing the respective group electrical contacts;

wherein the voltage in at least one of the at least four drive signals is varied so as to implement a chosen deformation mode or a chosen sequence of d31 and/or d33 deformation modes.

- 5 35. The method according to claim 34, wherein the method comprises:
- supplying a first drive signal to the first group of electrodes in the first electrode layer; and
 - supplying a second drive signal to the second group of electrodes in the first electrode layer; and
 - 10 - supplying a third drive signal to the first group of electrodes in the second electrode layer; and
 - supplying a fourth drive signal to the second group of electrodes in the second electrode layer.
- 15 36. The method according to claim 34 or claim 35, wherein:
- the first drive signal comprises a first holding signal, the second drive signal comprise a second holding signal, the third drive signal comprises a third holding signal and the fourth drive signal comprises a fourth holding signal; and wherein
- to deform and hold the ceramic member in d31 mode the holding signals are at
 - 20 voltages suitable to deform and hold the ceramic member in d31 mode for a chosen duration;
 - to deform and hold the ceramic member in d33 mode the holding signals are at voltages suitable to deform and hold the ceramic member in d33 mode for a chosen duration;
 - to hold the ceramic member in an undeformed position the first, second, third and fourth holding signals are all at the same voltage and remain so for a chosen duration; and
- 25 wherein the method comprises:
- choosing the desired position of the ceramic member and:
 - supplying the appropriate drive signals to their respective groups of electrodes so as to hold the ceramic member in said desired position.
- 30 37. The method according any of claims 34 to 36, wherein the method comprises using a drive signal according to any of claims 14 to 27 so as to move the ceramic member.

38. The method according to any of claims 28 to 33, wherein the method comprises controlling a switching circuit so as to connect and disconnect a first drive signal and/or a second drive signal of the at least two drive signals from the respective group electrical contacts in order to implement the chosen deformation mode or the chosen sequence of d31 and/or d33 deformation modes.

39. The method according to claim 38, wherein the first drive signal supplies the first voltage and wherein the second drive signal supplies the second voltage.

40. A method of sensing using an electrical sensor element, wherein said electrical sensor element comprises:

a ceramic member, wherein said ceramic member comprises at least one ceramic layer having a depth; and

first and second electrode layers disposed adjacent the at least one ceramic layer in the depth direction, such that a potential difference may be established through at least a portion of the ceramic layer during operation;

wherein said electrical sensor element is arranged adjacent to a flexible membrane, and

wherein the first electrode layer comprises a first group of electrodes comprising at least two fingers and a second group of electrodes comprising at least one finger;

wherein the fingers of the first and second groups of electrodes are arranged alternately in the first electrode layer in an interdigitation direction; and

wherein the second electrode comprises a first group of electrodes comprising at least two fingers and a second group of electrodes comprising at least one finger;

wherein the fingers of the first and second group of electrodes are arranged alternately in the second electrode layer in the interdigitation direction; and

wherein for each group of electrodes all the fingers in said group are electrically connected to each other and to a group electrical contact; and

wherein the first group of electrodes of the first electrode layer at least partially overlap in the interdigitation direction with the first group of electrodes of the second electrode layer; and

wherein the second group electrodes of the first electrode layer at least partially overlap in the interdigitation direction with the second group of electrodes of the second electrode layer; and

wherein the ceramic member can be deformed in d31 mode or d33 mode; and

5 wherein the method comprises the flexible membrane moving in response to an external force and said electrical sensor element thereby deforming and said ceramic member thereby deforming in d31 or d33 mode so as to generate an electrical signal or signals which are supplied to one or more of the group electrical contacts wherein said group electrical contacts are configured as outputs.

10

41. The method according to claim 40, wherein said method further comprises measuring the generated electrical signal or signals supplied to the one or more group electrical contacts and using said signal or signals to determine the deformation of the flexible membrane and hence determining the strength of the external force.

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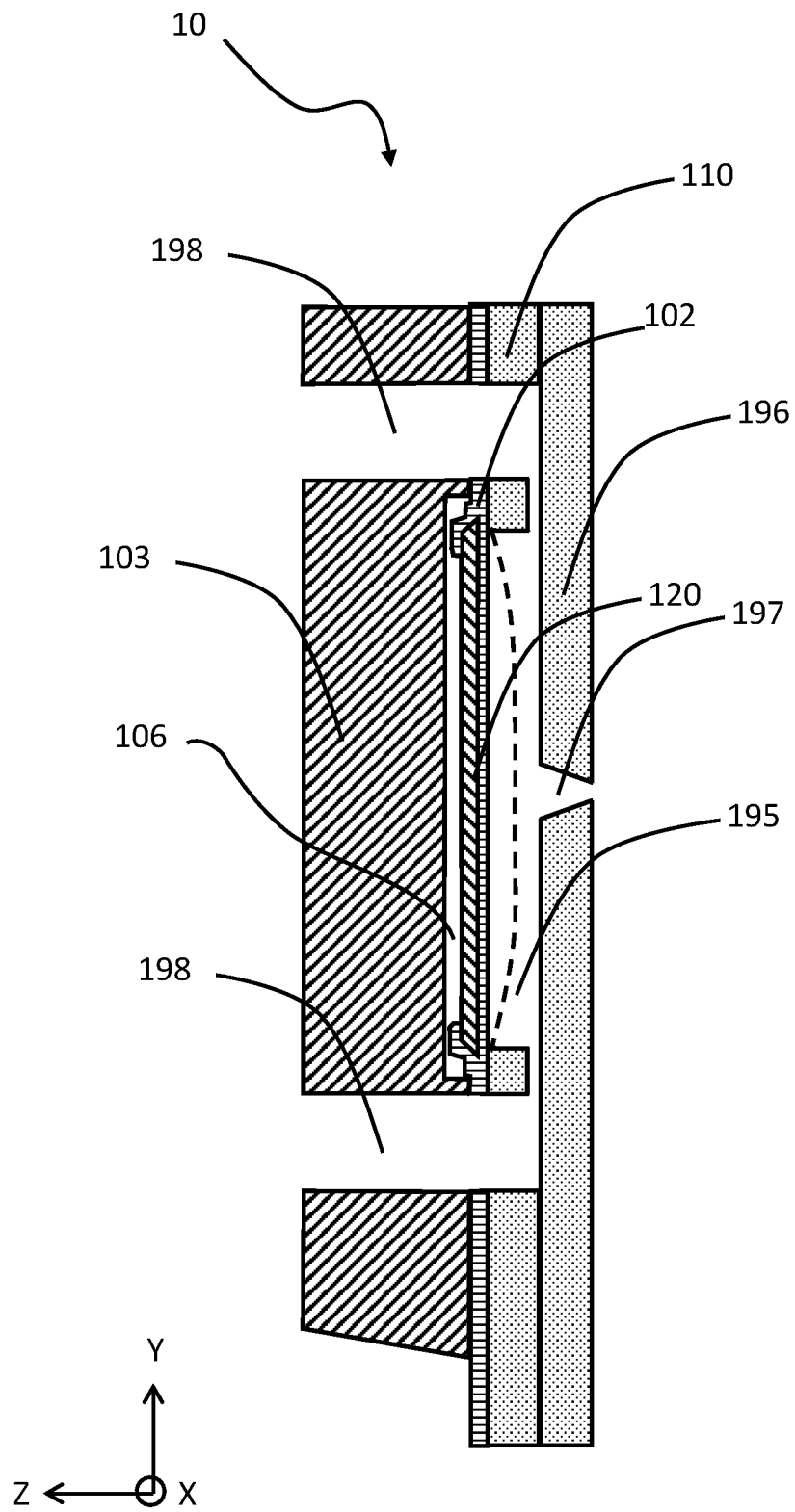


Fig. 1A

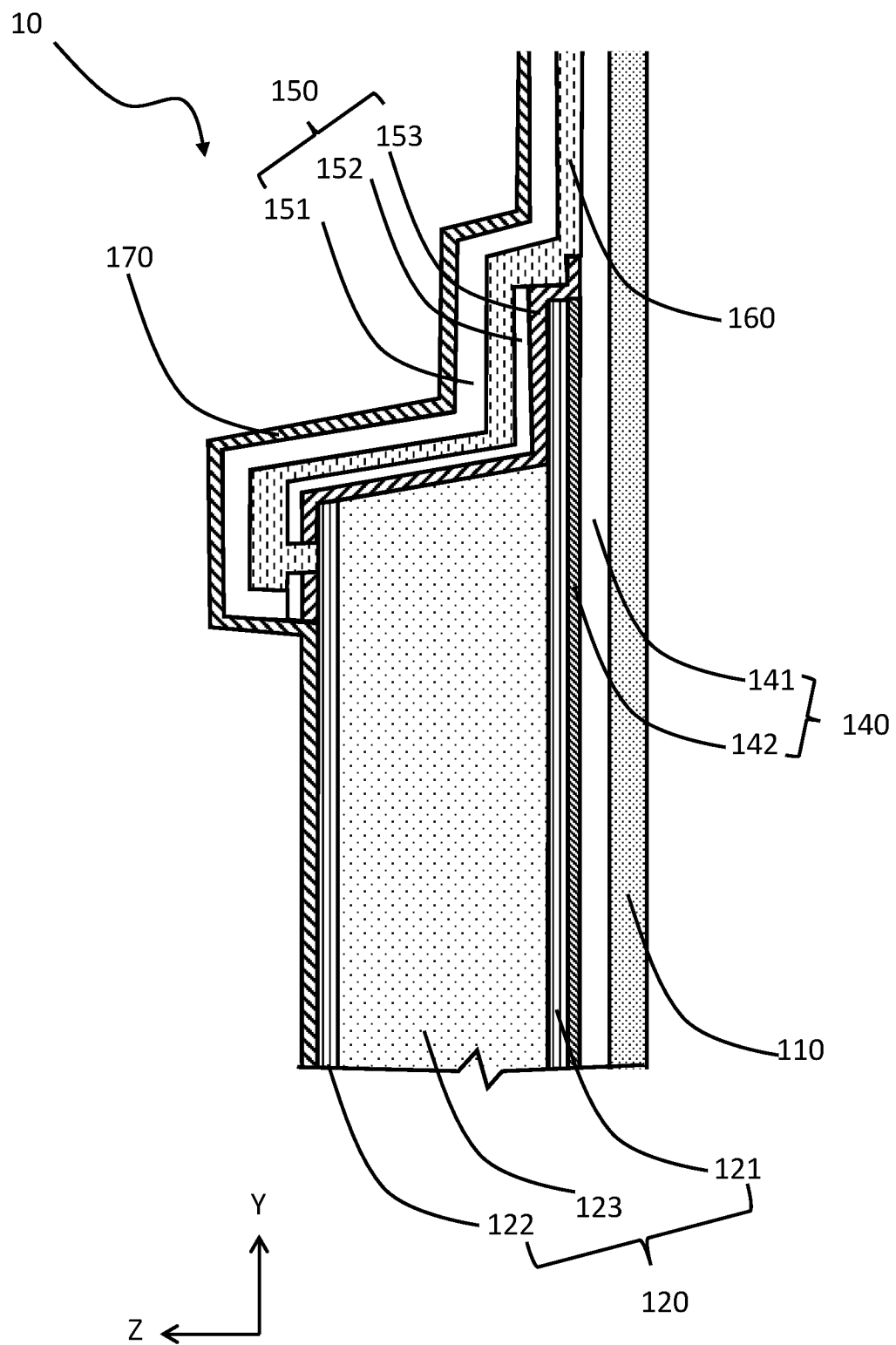
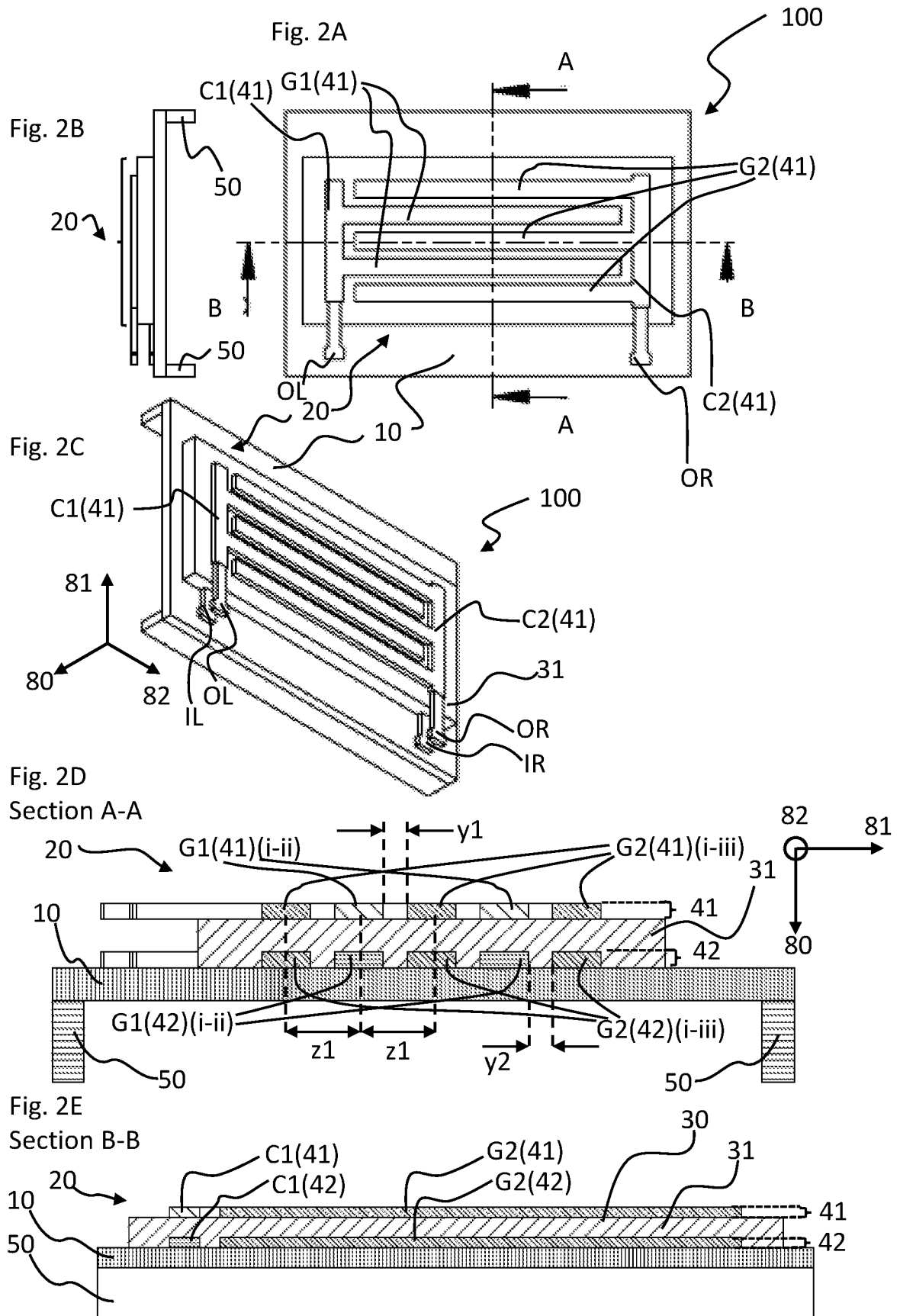


Fig. 1B



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Fig. 3A

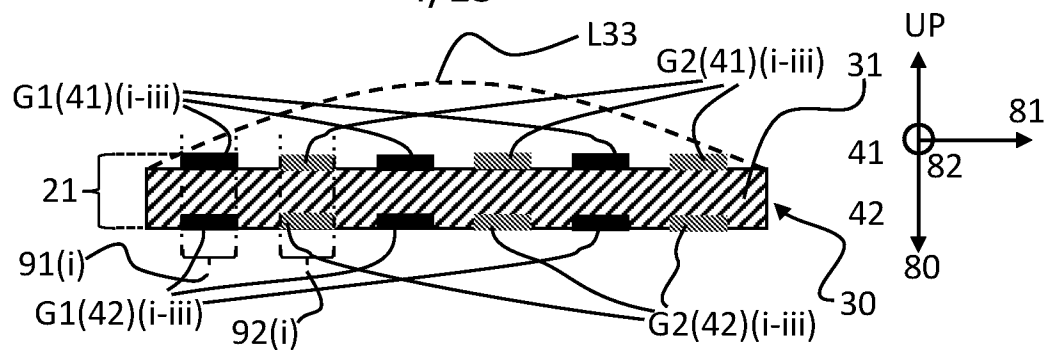


Fig. 3B

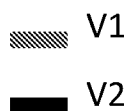
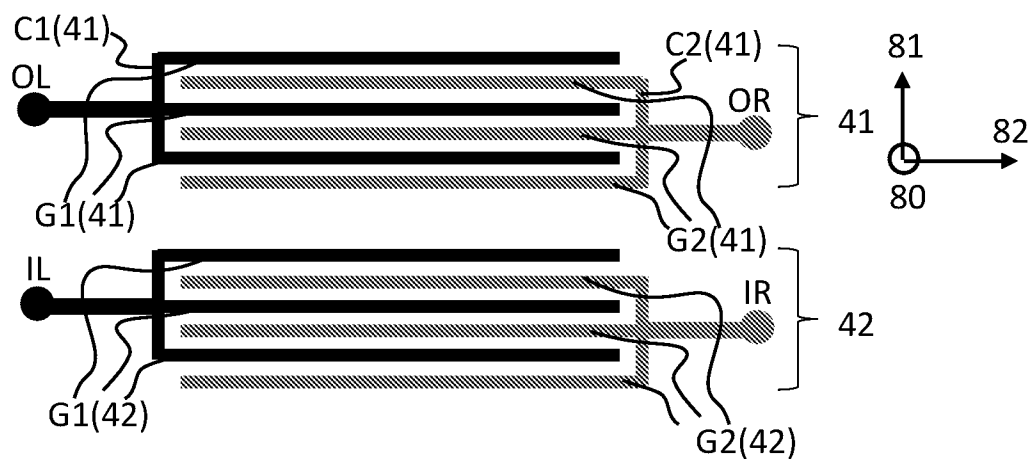


Fig. 4A

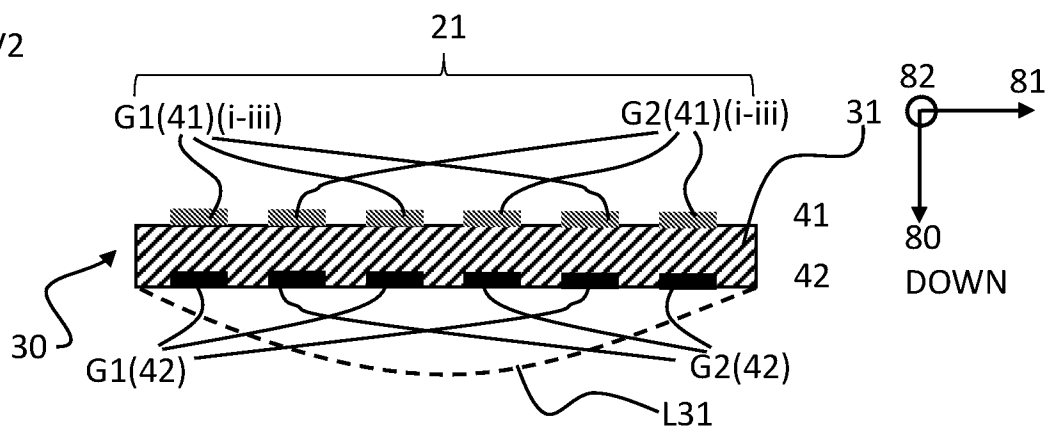
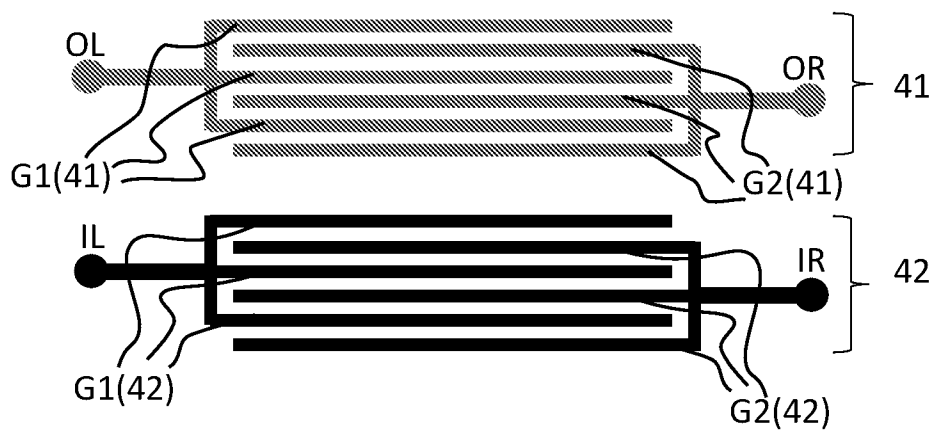
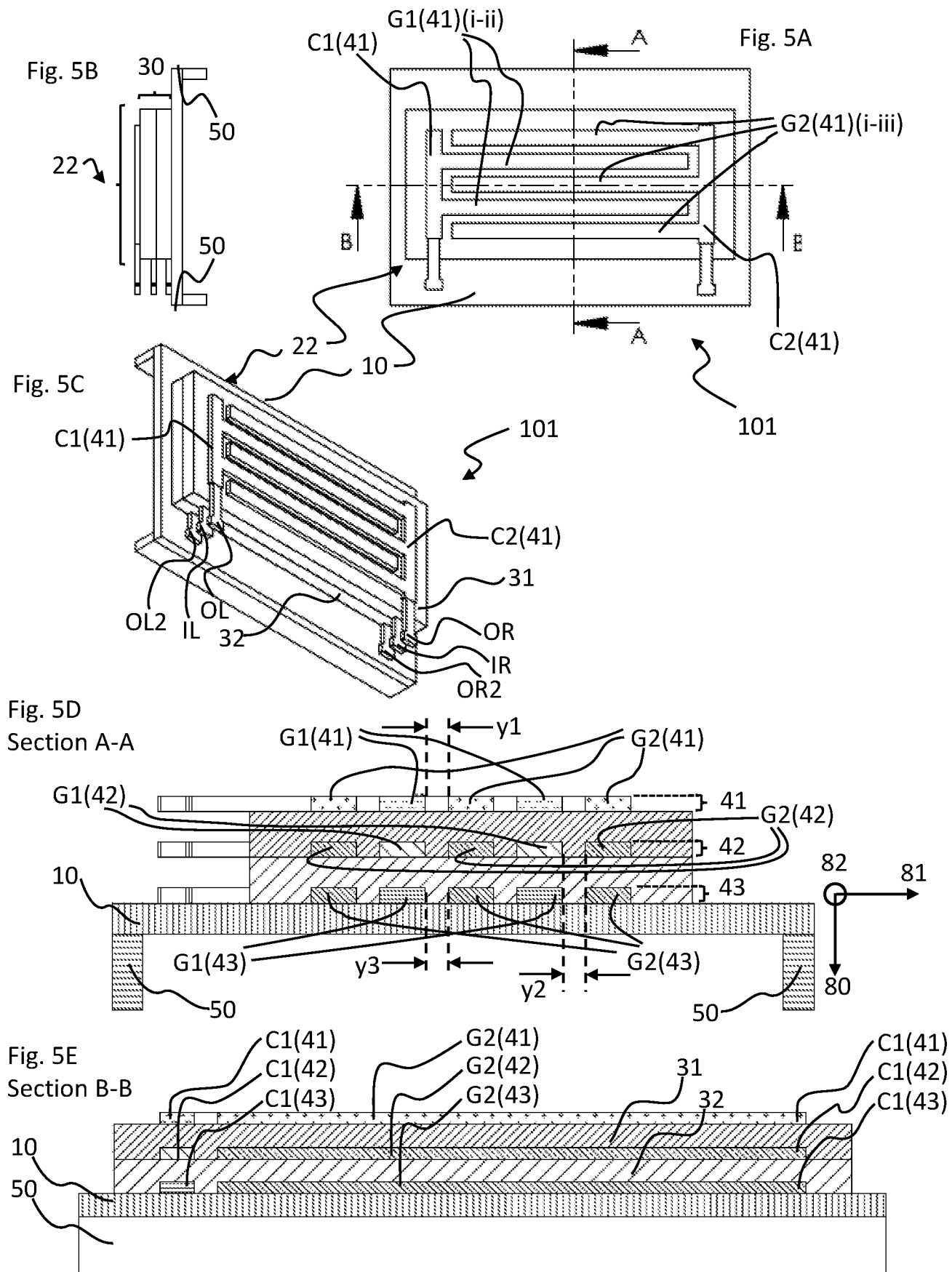


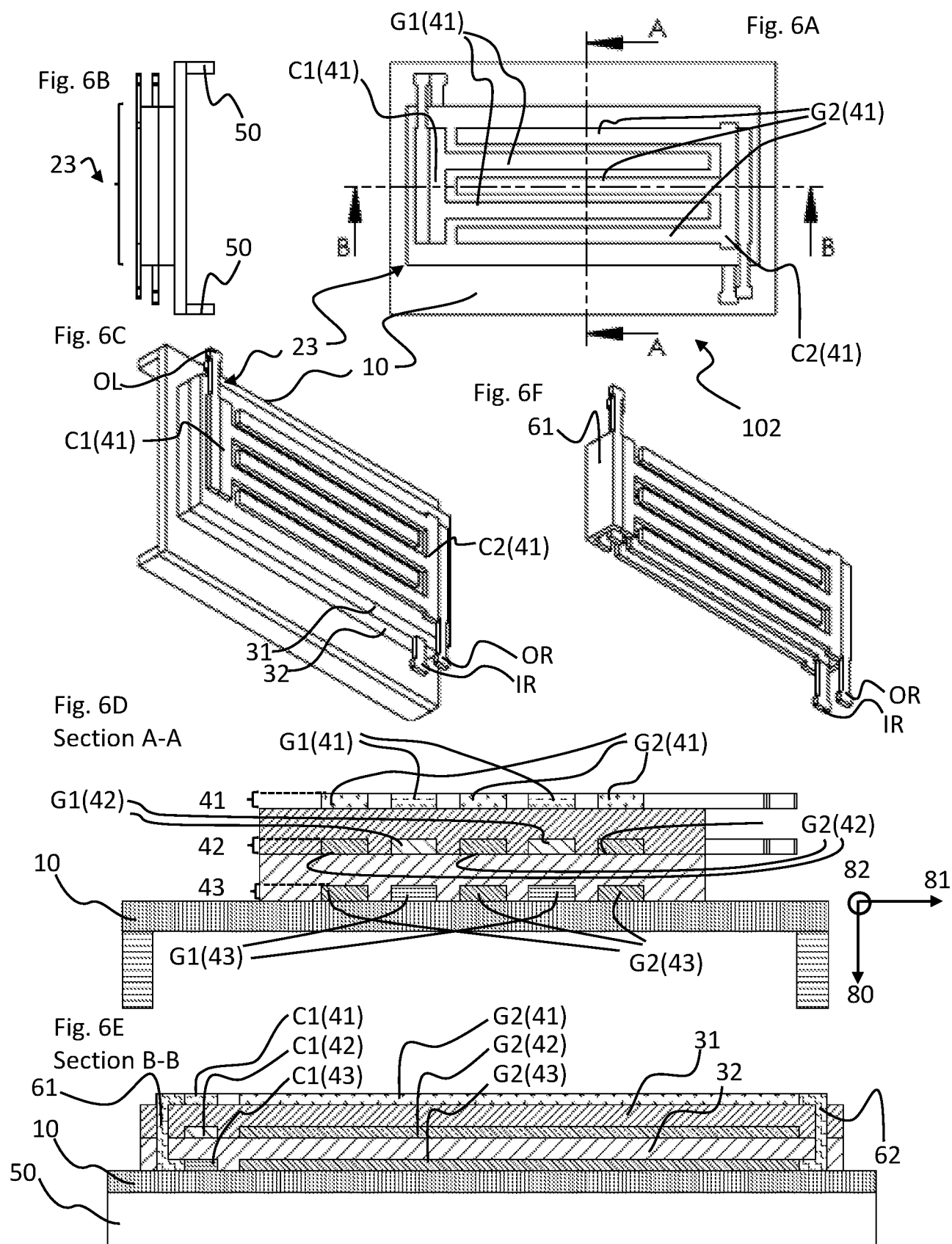
Fig. 4B



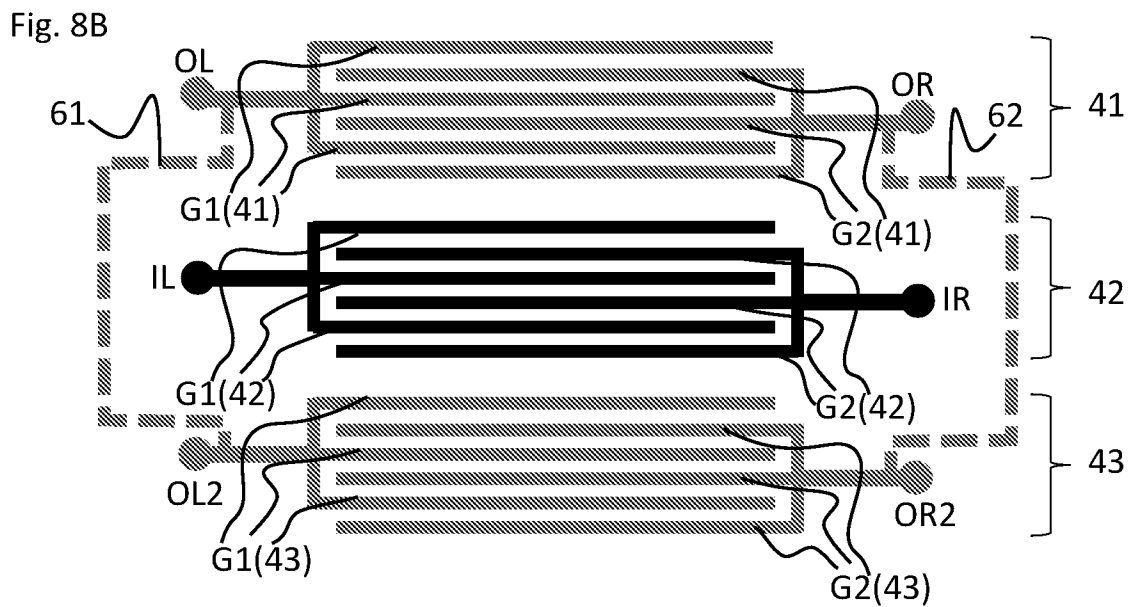
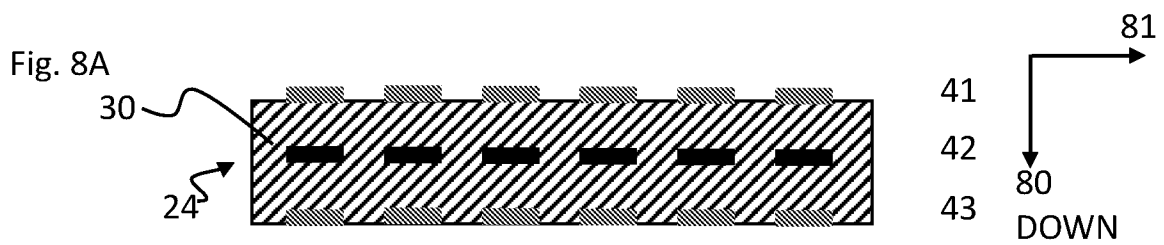
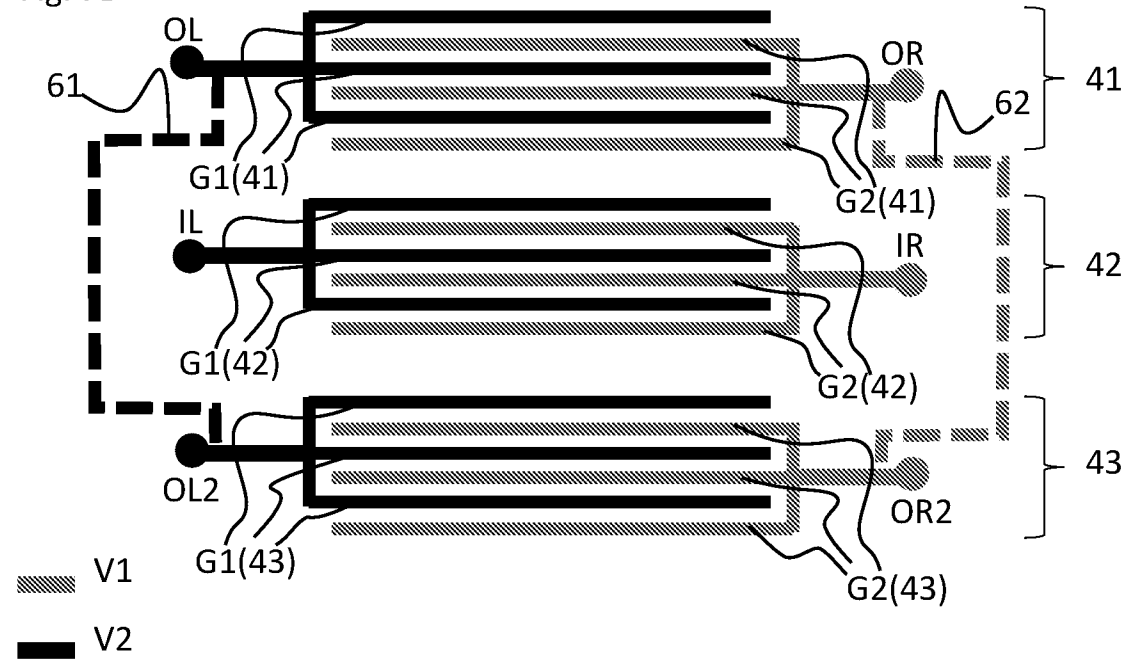
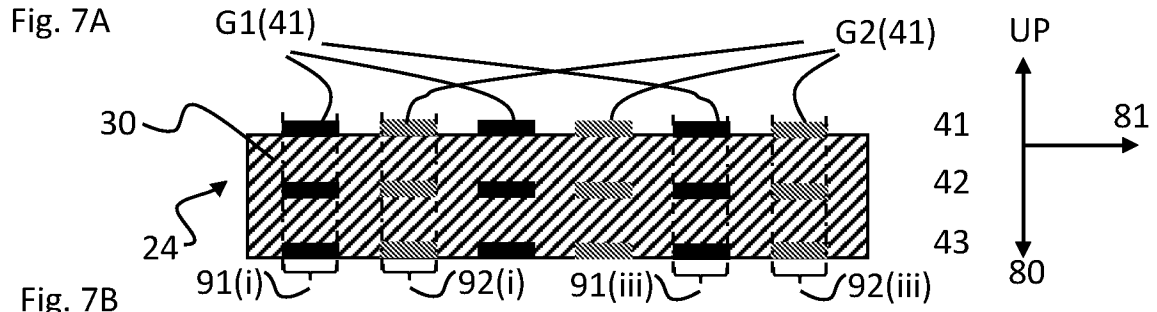
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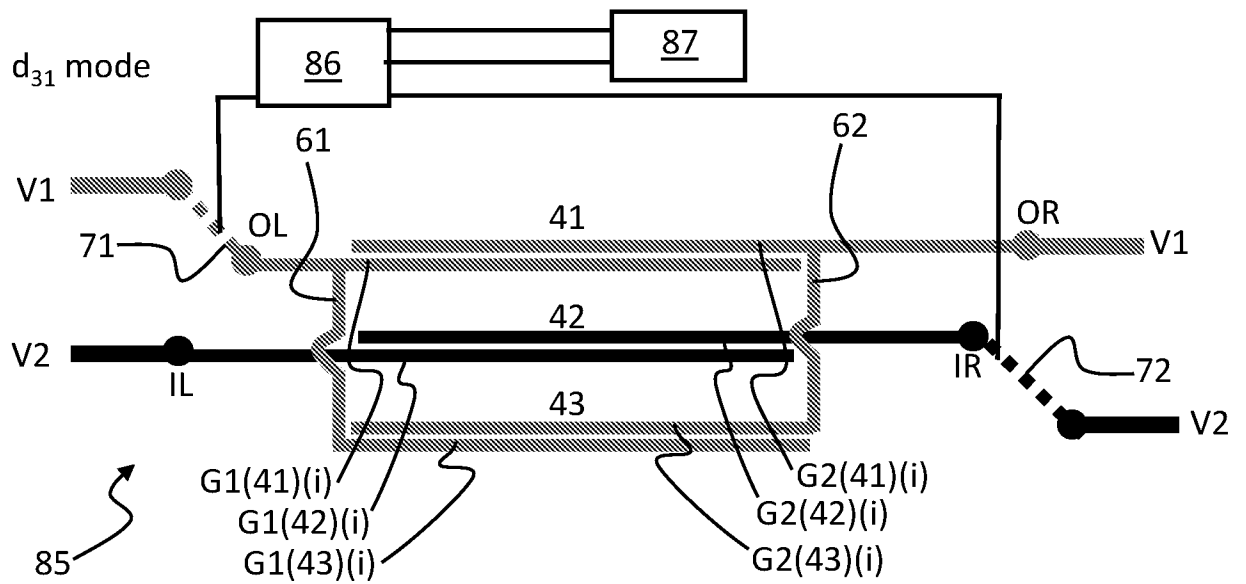
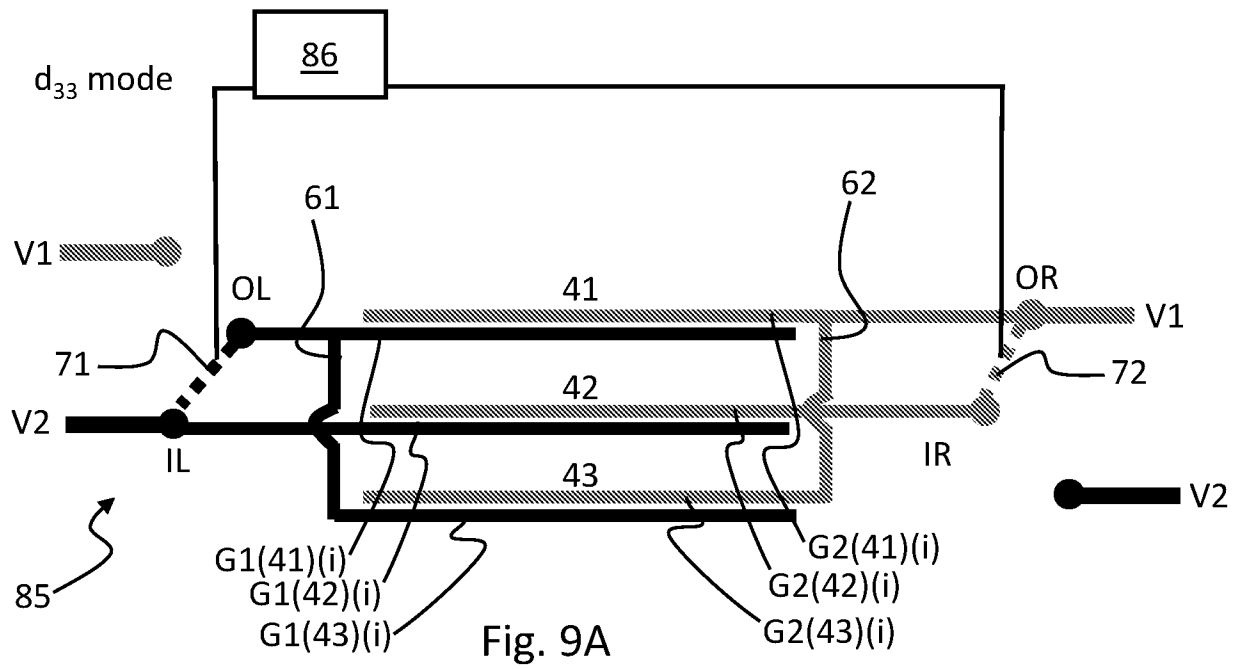


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▨ V1 (e.g. ground)

▬ V2 (e.g. 10V)

Fig. 10A

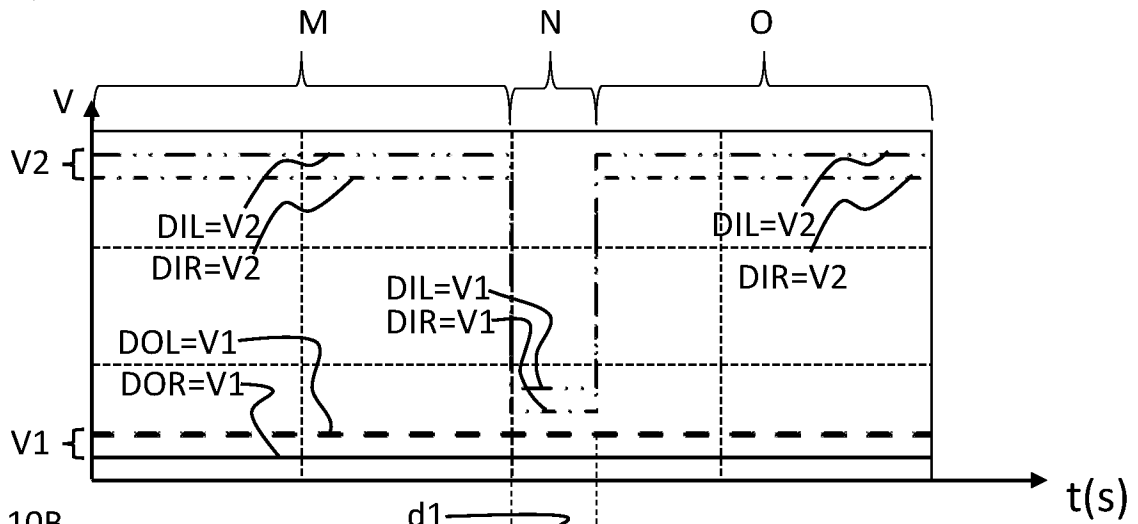


Fig. 10B

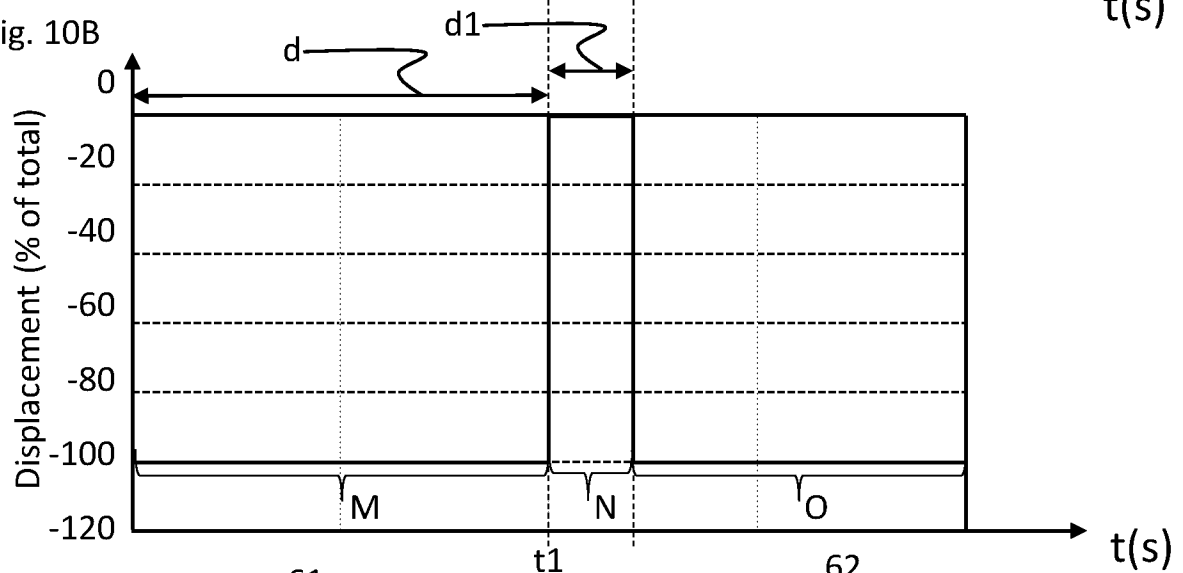


Fig. 10C
(i & O) d31

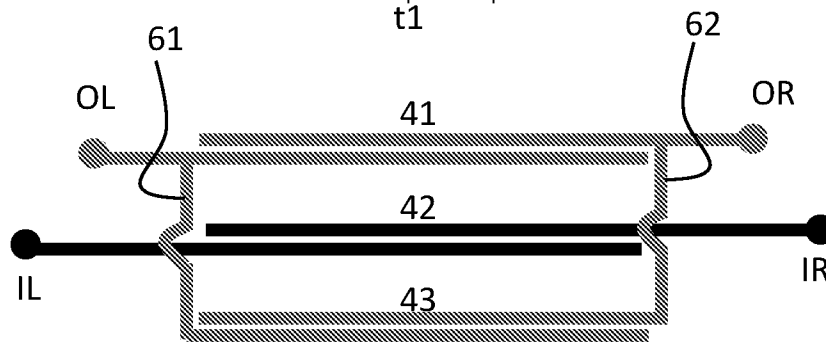


Fig. 10D
(ii) neutral

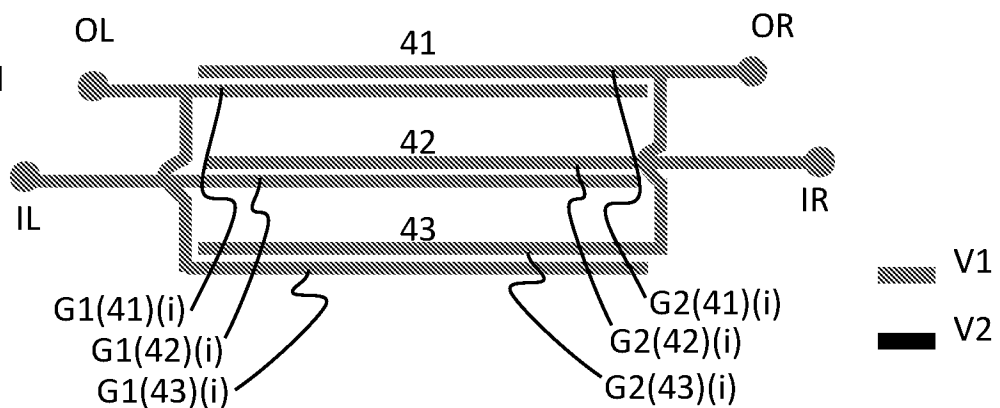


Fig. 11A

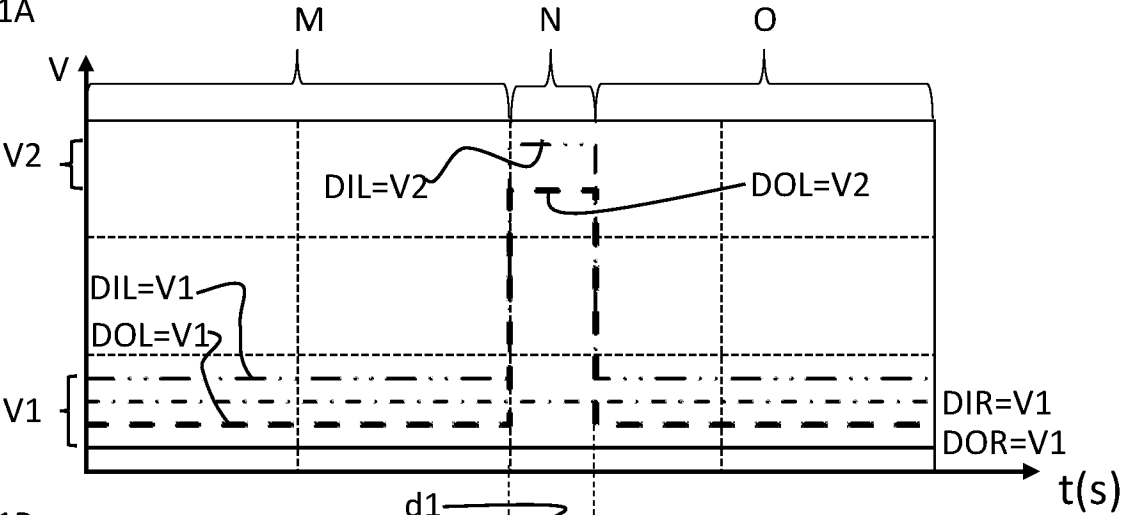


Fig. 11B

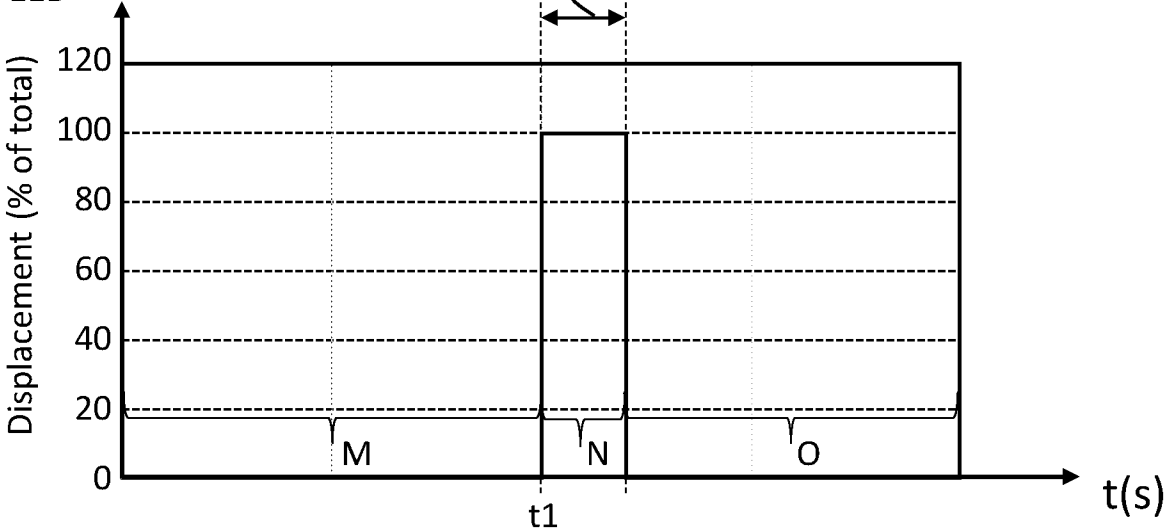


Fig. 11C

(M & O) neutral

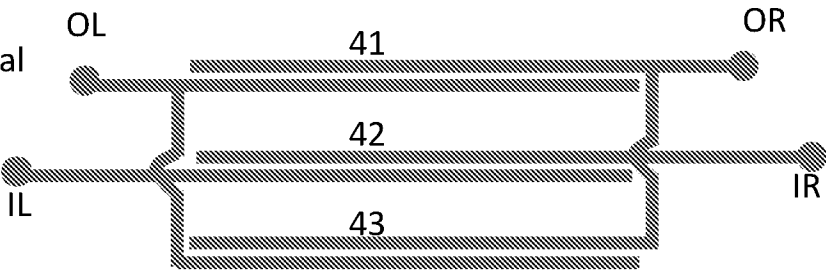
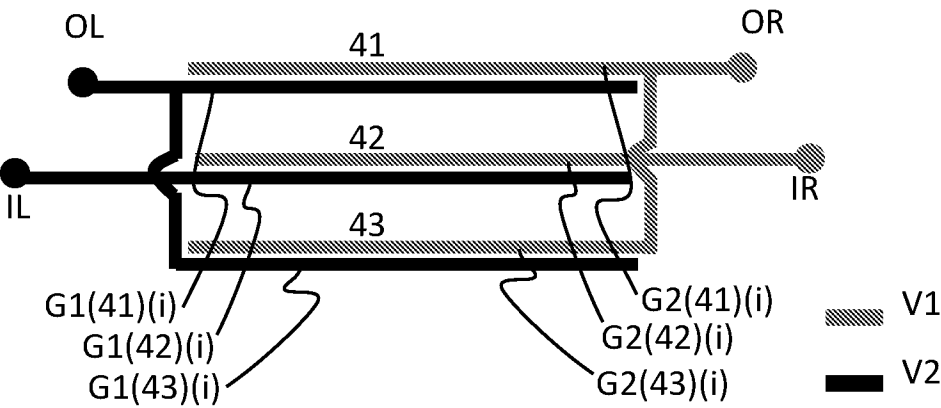


Fig. 11D

(N) d33



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Fig. 12A

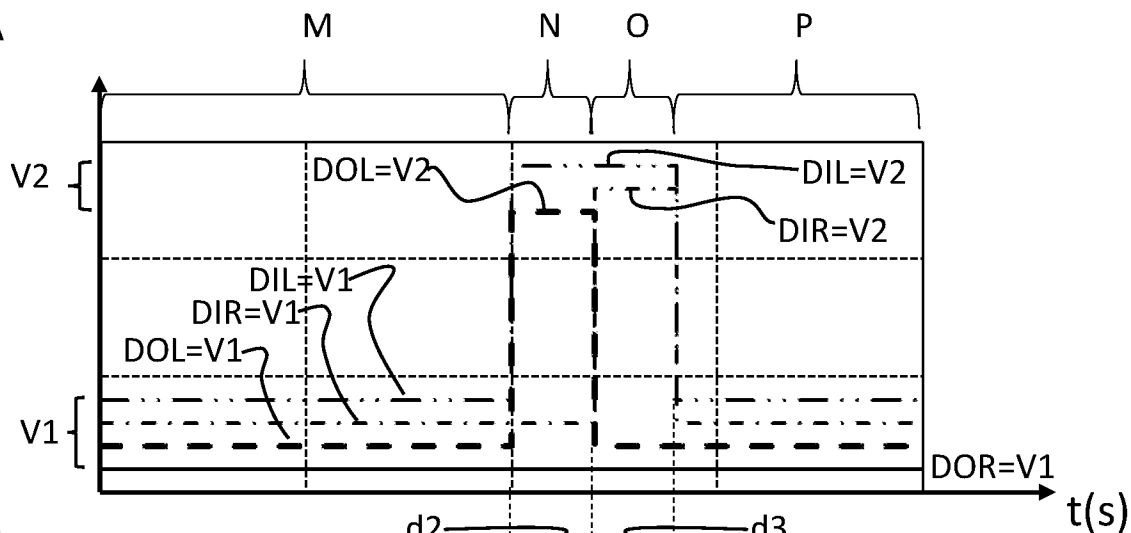


Fig. 12B

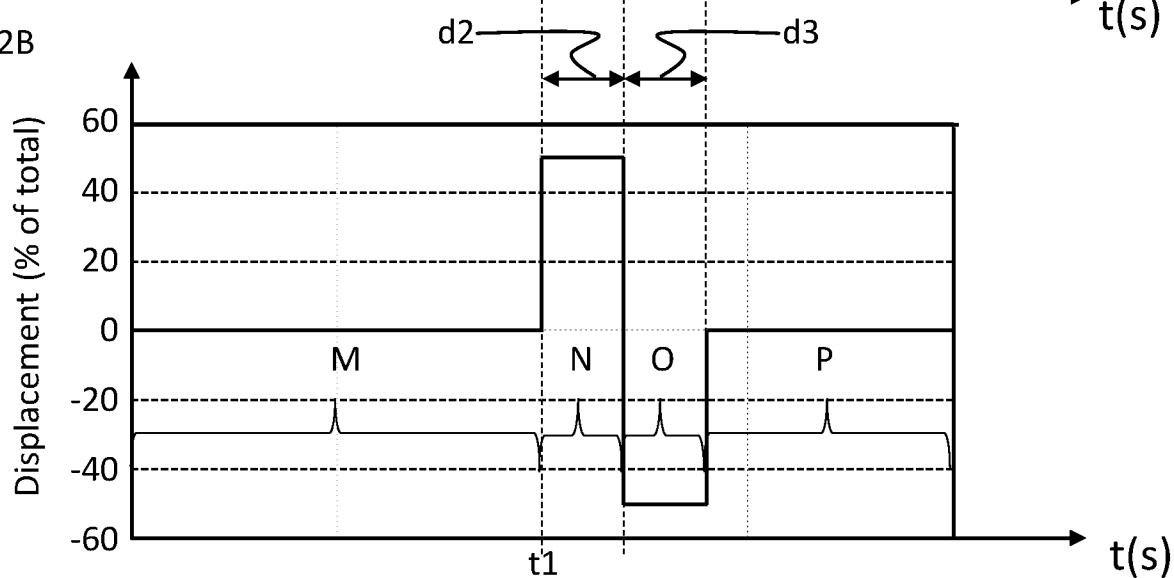


Fig. 12C
(M & P) neutral

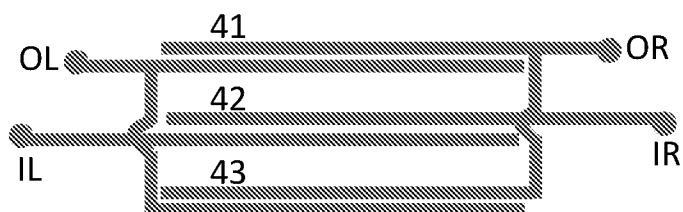


Fig. 12D
(N) d33

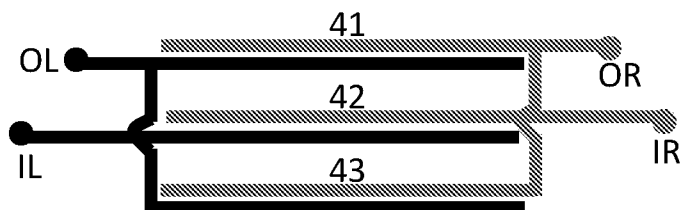
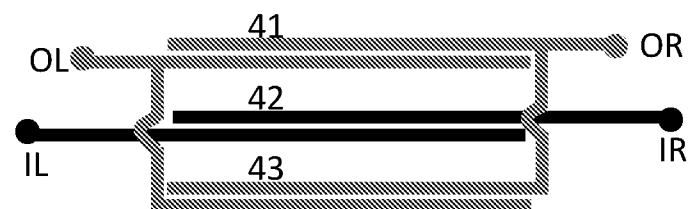


Fig. 12E
(O) d31



V1
 V2

Fig. 13A

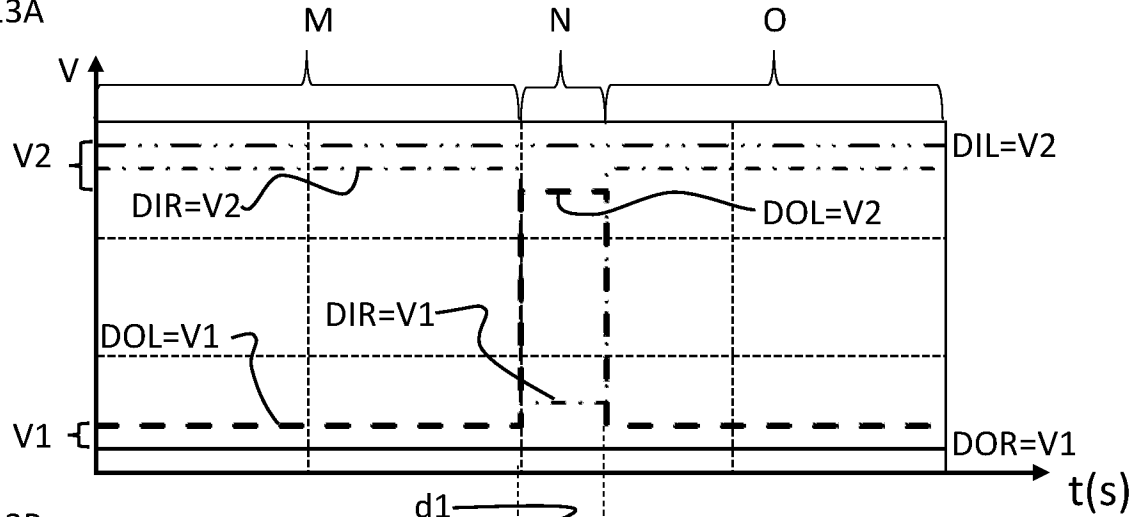


Fig. 13B

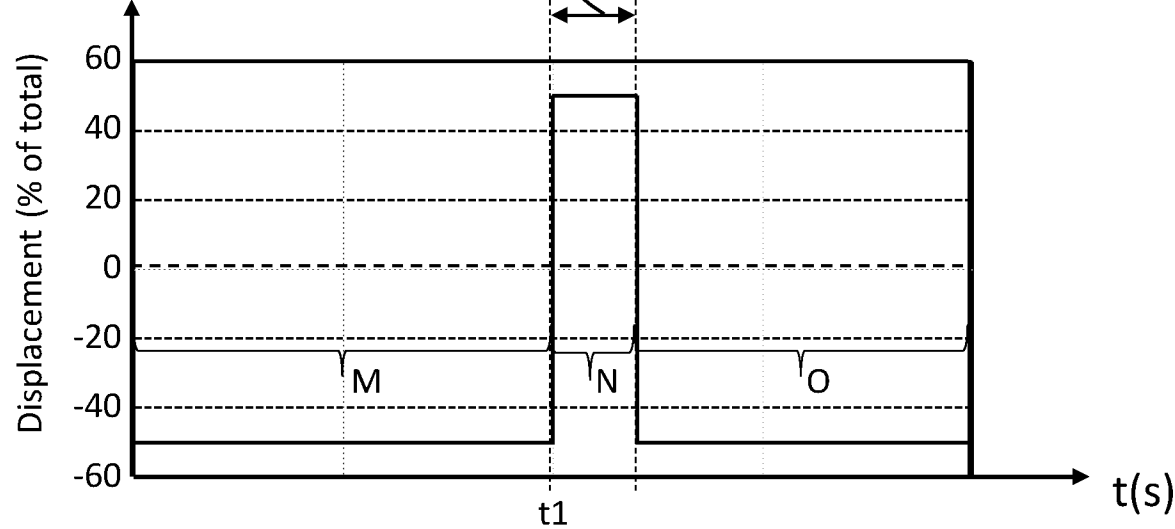


Fig. 13C
(M & O) d31

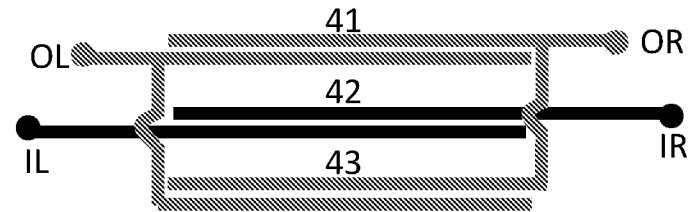
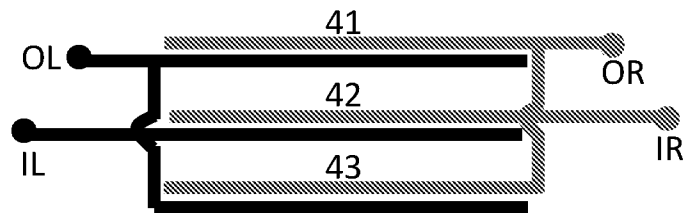


Fig. 13D
(N) d33



 V1
 V2

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Fig. 14A

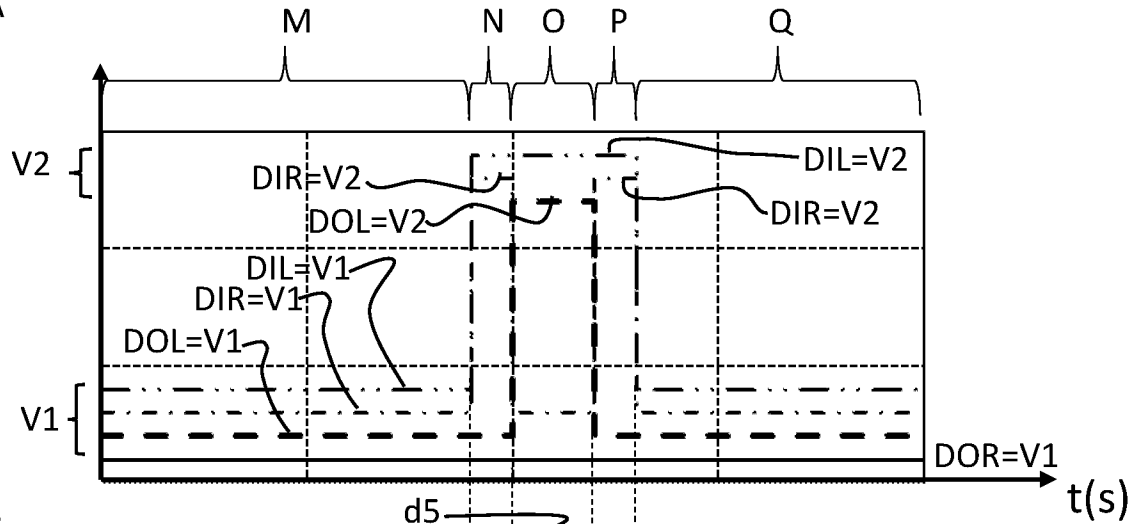


Fig. 14B

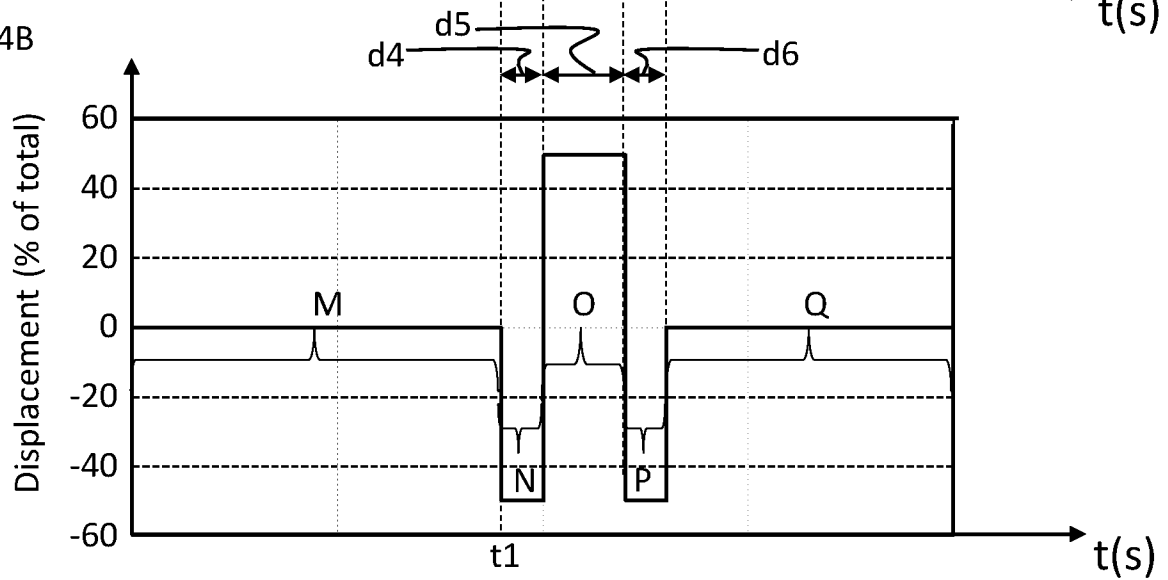


Fig. 14C
(M & Q) neutral

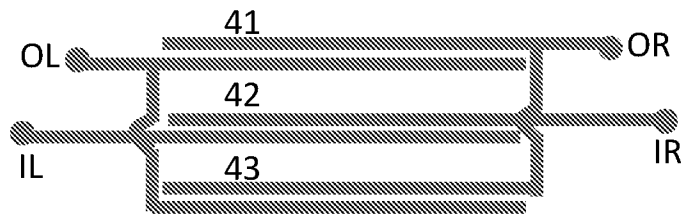


Fig. 14D
(N & P) d31

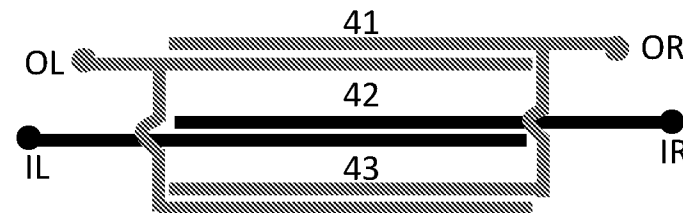
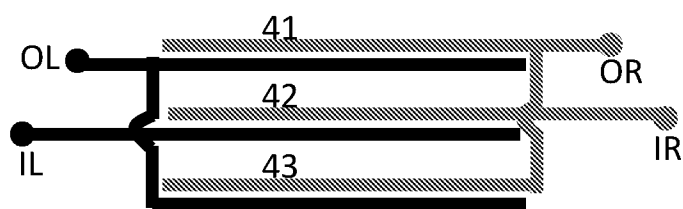


Fig. 14E
(O) d33



 V1
 V2

Fig. 15A

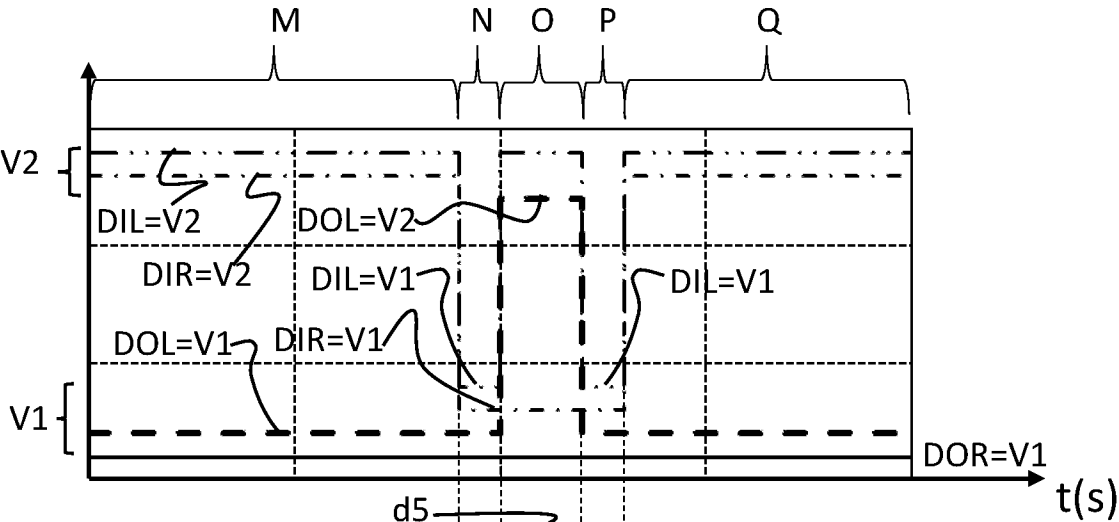


Fig. 15B

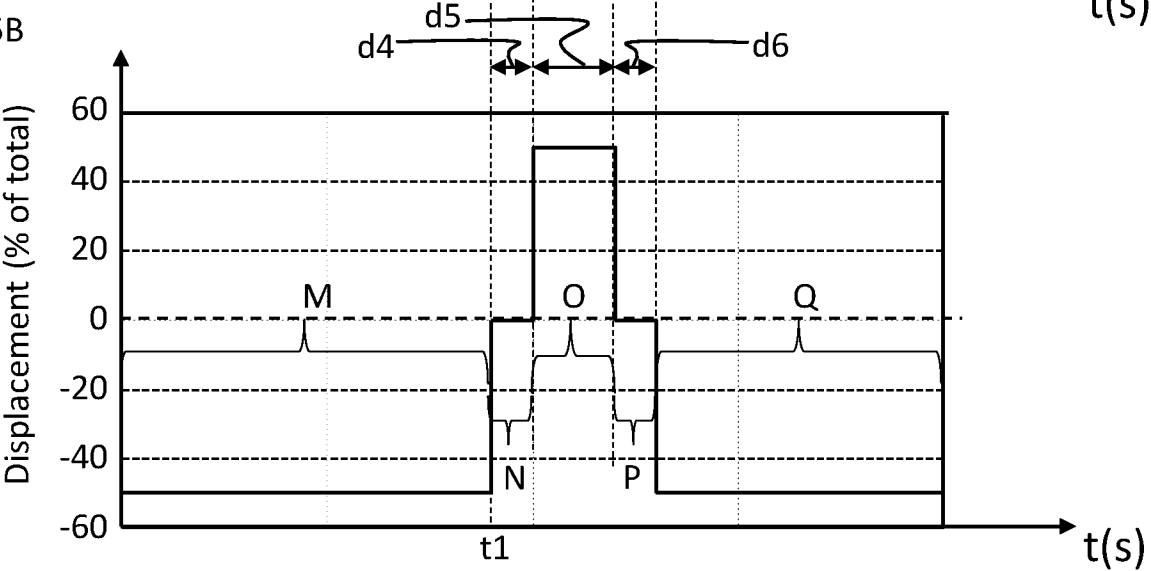


Fig. 15C
(M & Q) d31

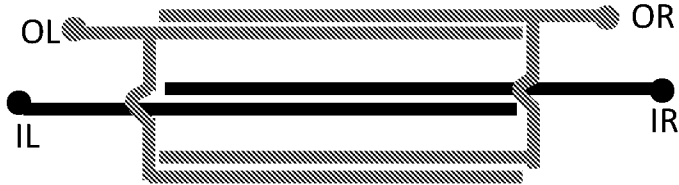


Fig. 15D
(N & P) neutral

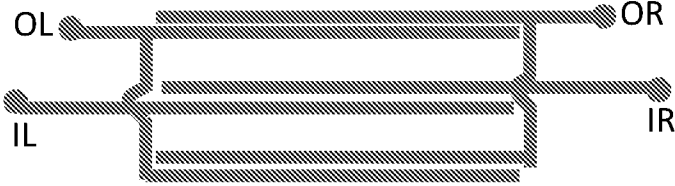
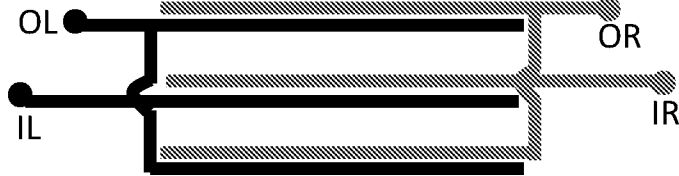


Fig. 15E
(O) d33



 V1
 V2

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Fig. 16A

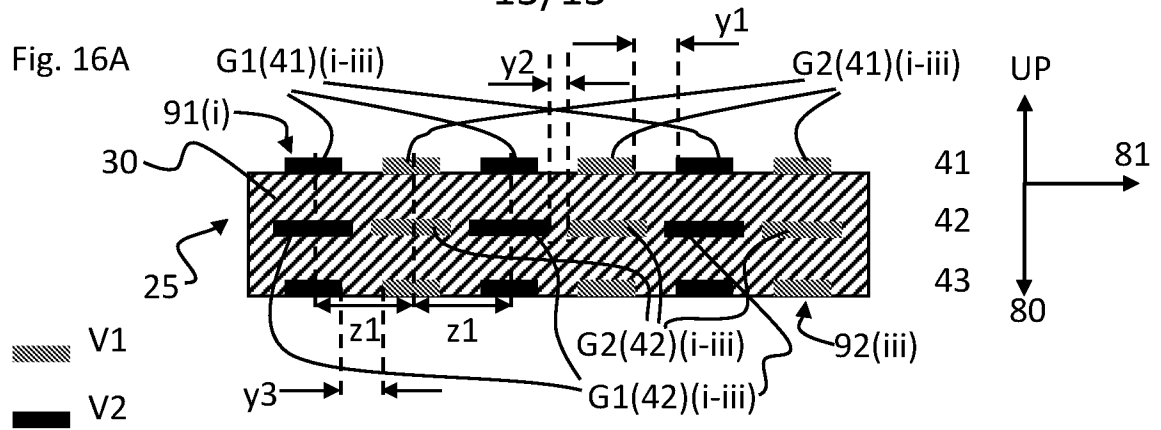


Fig. 16B

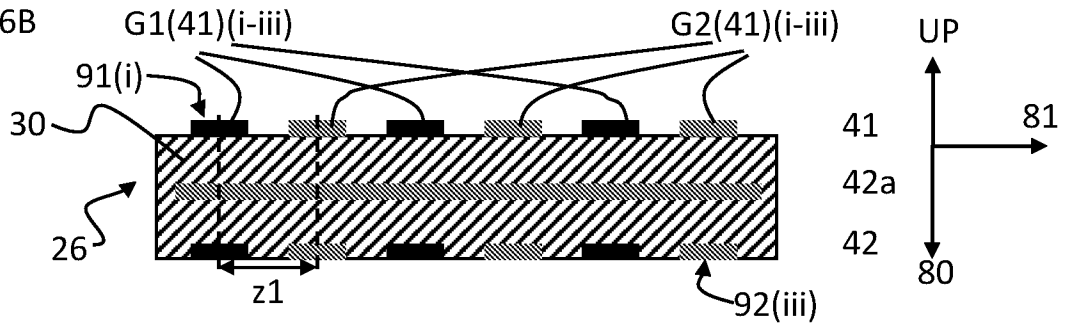


Fig. 16C

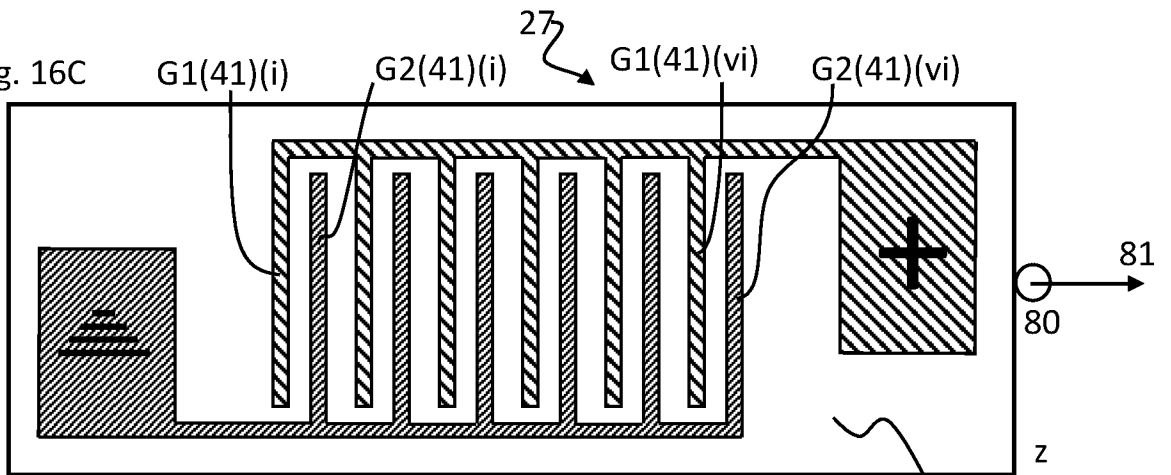
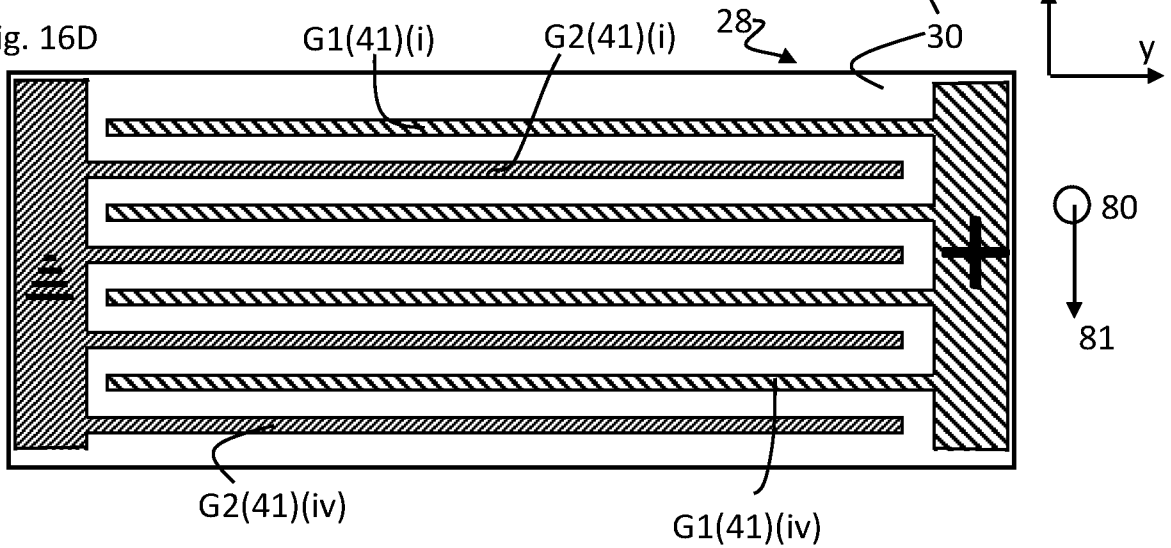


Fig. 16D



INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2021/053317

A. CLASSIFICATION OF SUBJECT MATTER

INV. H01L41/047 H01L41/04 H01L41/09 H01L41/113 B41J2/14
ADD.

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)

H01L

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

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

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2013/021305 A1 (ZUO ET AL) 24 January 2013 (2013-01-24)	1-7, 9-11, 14-27, 40, 41
A	paragraphs [0003], [0069], [0086] figures 1, 2 -----	8, 12, 13, 28-39
X	ZHOU ET AL: "Investigation of modified Lamé mode resonator with high coupling coefficient", JOURNAL OF APPLIED PHYSICS, vol. 127, no. 7, 19 February 2020 (2020-02-19), XP012244796, ISSN: 0021-8979, DOI: 10.1063/1.5142758 [retrieved on 2020-02-19]	1-7, 9-11, 14-27, 40, 41
A	IV. Geometry optimization figures 1, 5d -----	8, 12, 13, 28-39
-/--		



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

31 March 2022

Date of mailing of the international search report

20/04/2022

Name and mailing address of the ISA/

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Authorized officer

Subke, Kai-Olaf

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2021/053317

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 7 429 801 B2 (MICHELIN) 30 September 2008 (2008-09-30)	1-7, 9-11, 14-27, 40, 41
A	column 5, lines 25-31 figure 2a	8, 12, 13, 28-39
X	EP 2 549 556 B1 (LUXEMBOURG INST) 22 April 2015 (2015-04-22)	1-7, 9-11, 14-27, 40, 41
A	figures 1b, 2	8, 12, 13, 28-39
X	GB 2 579 041 A (XAAR) 10 June 2020 (2020-06-10)	14-27
A	figure 5	1-13, 28-41

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/GB2021/053317

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			JP 2022511707 A	01-02-2022
			US 2022006000 A1	06-01-2022
			WO 2020099891 A1	22-05-2020
