

(54) Title of the Invention: **An actuator component for a droplet ejection head and method for manufacturing the same**

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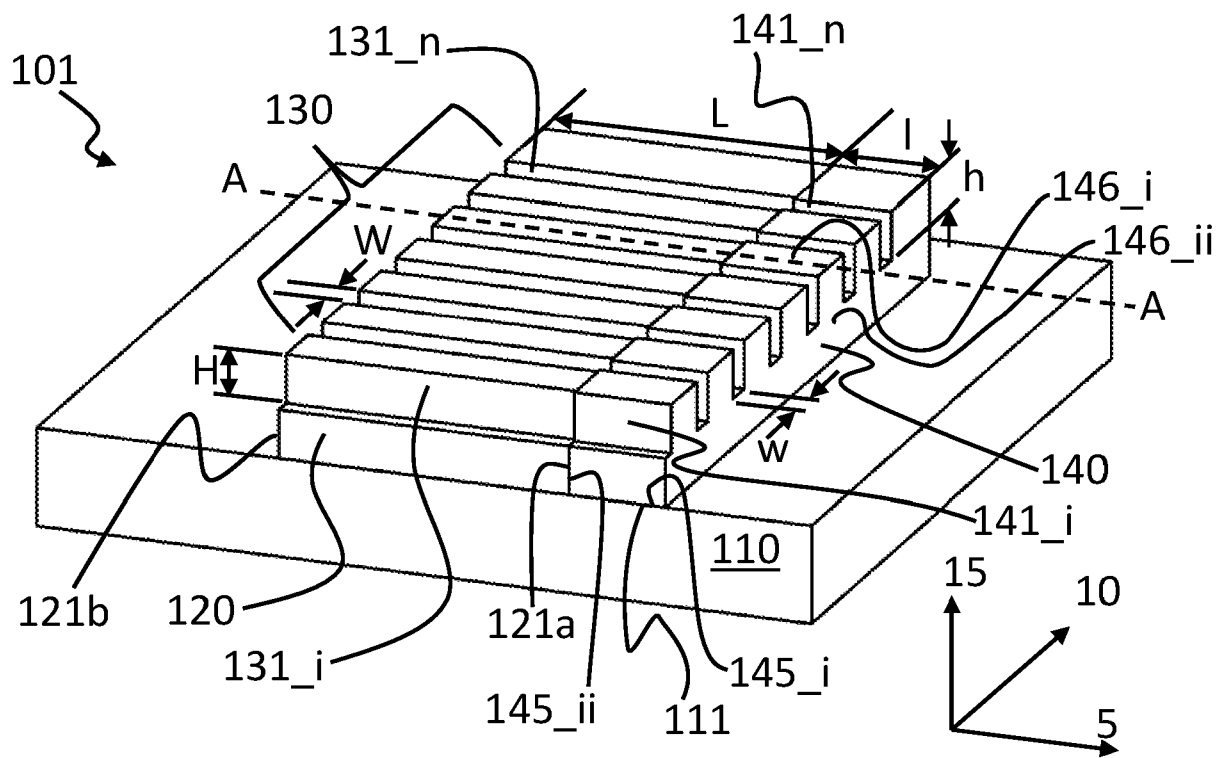


Figure 1

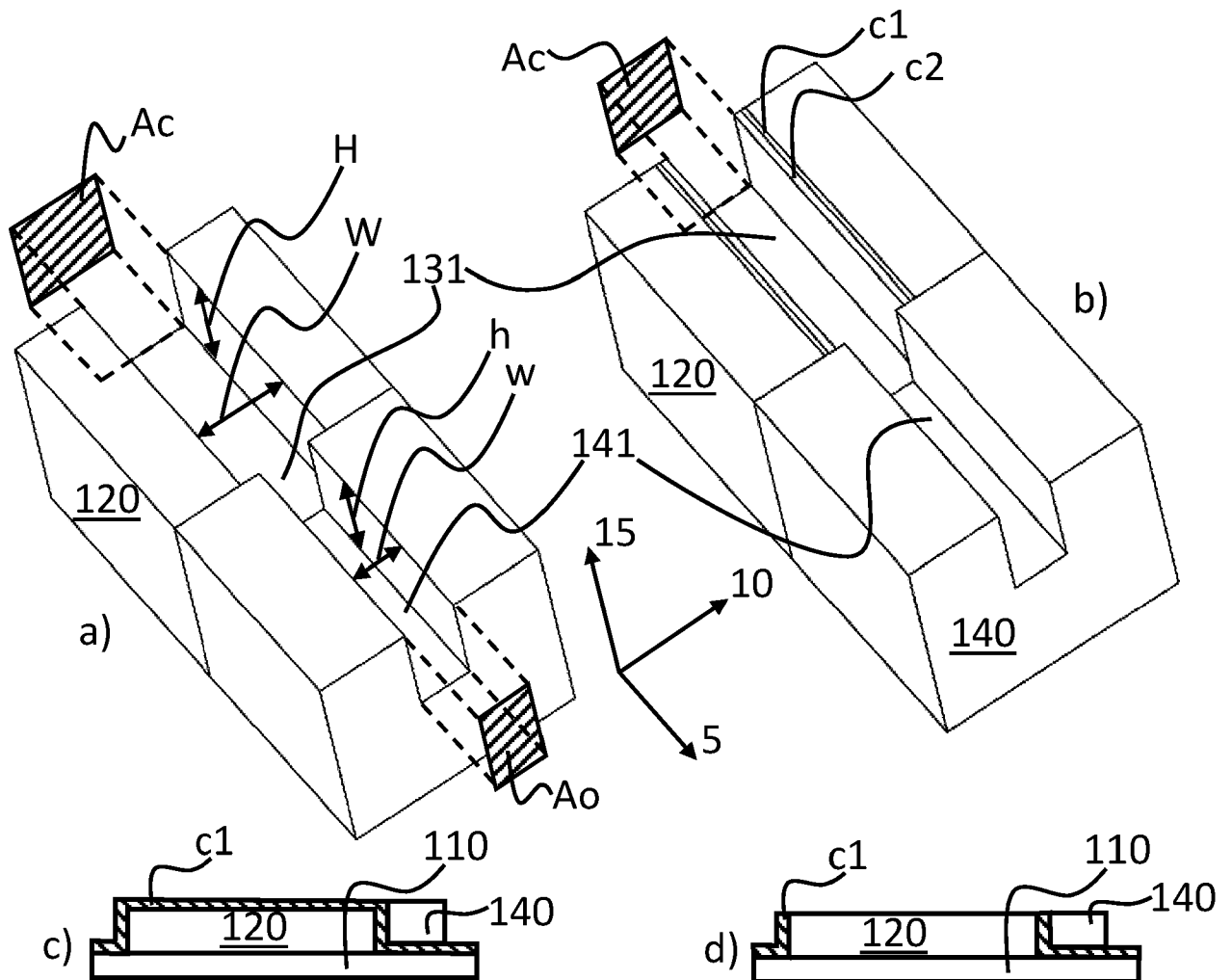


Figure 2

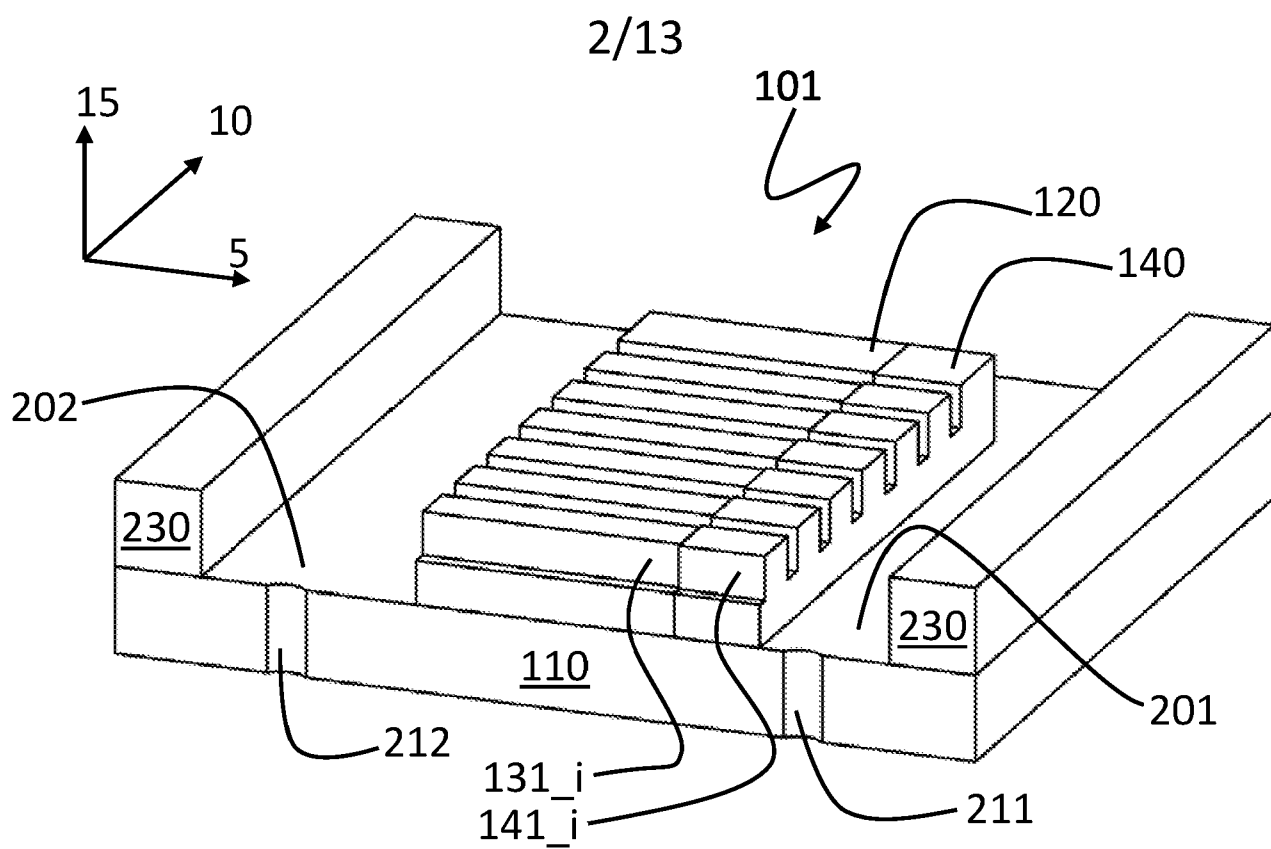


Figure 3

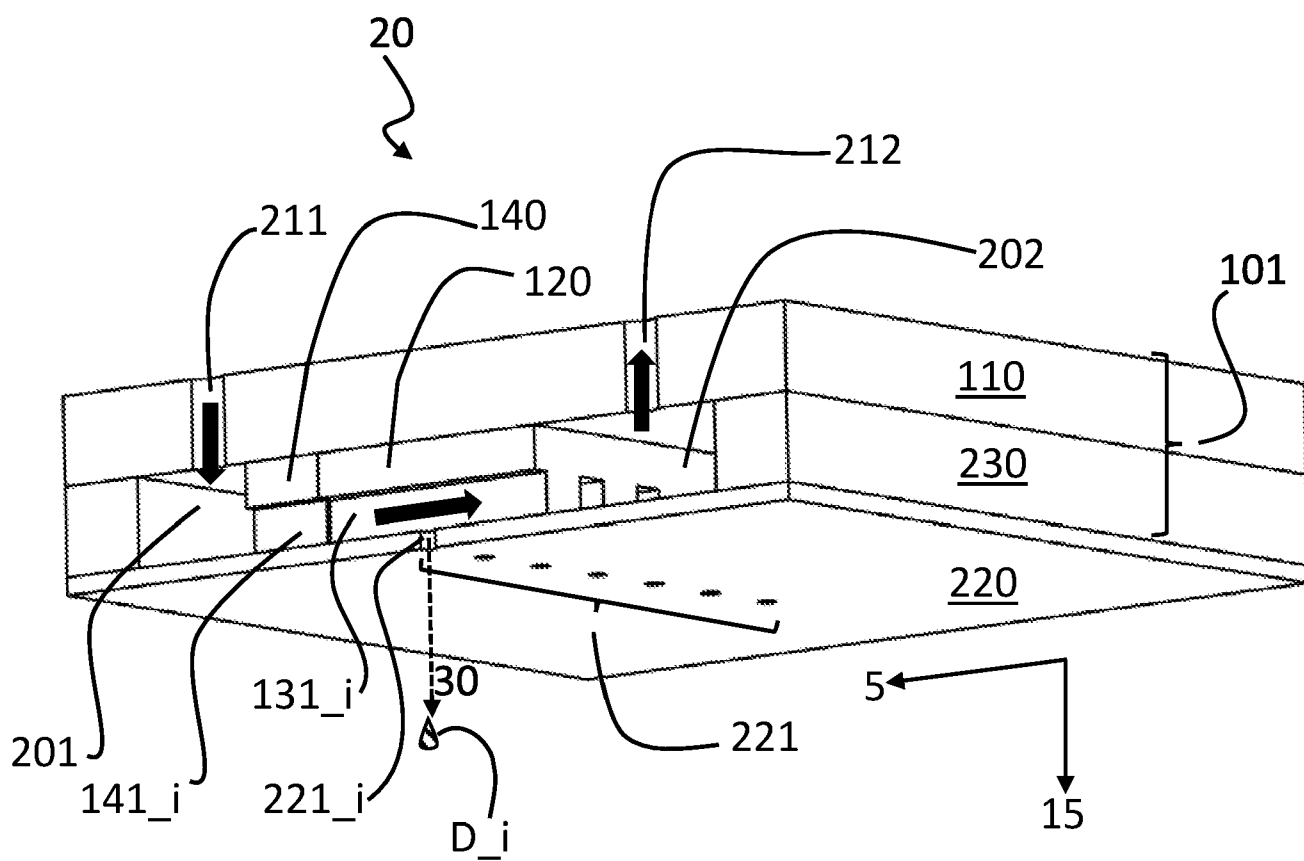


Figure 4

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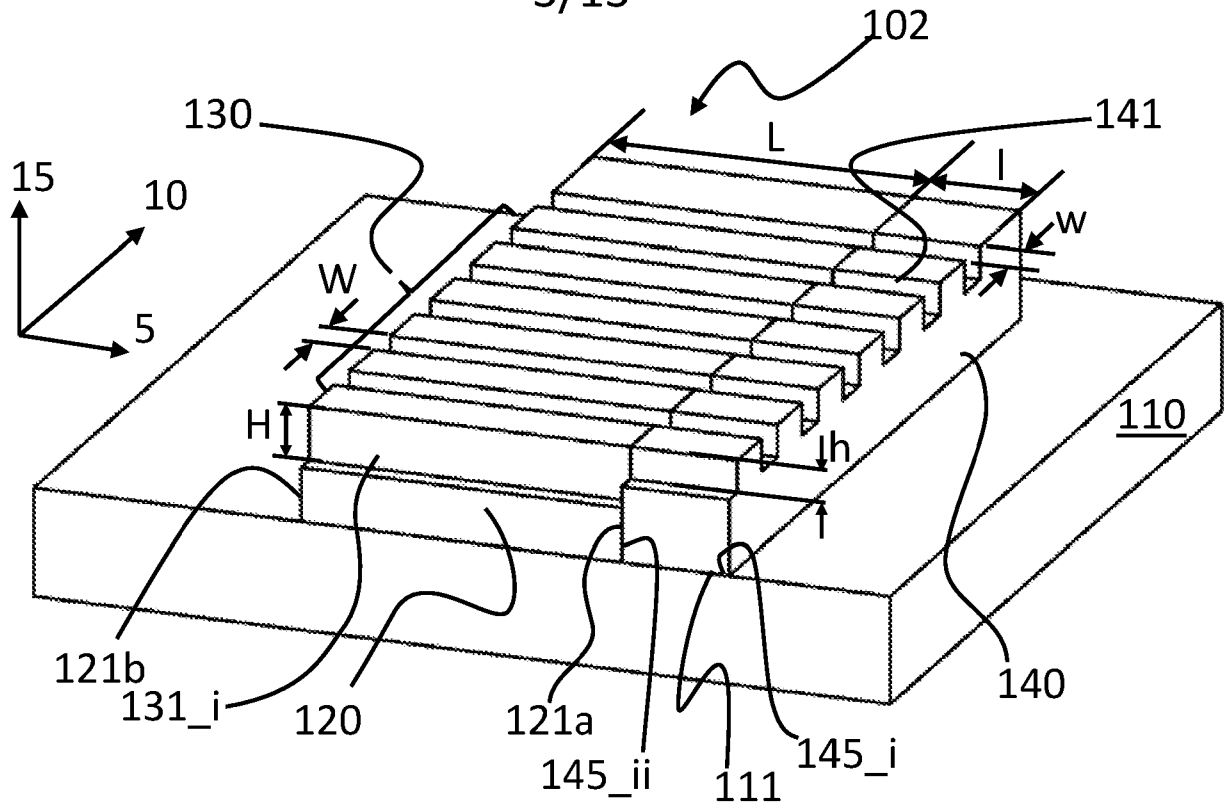


Figure 5

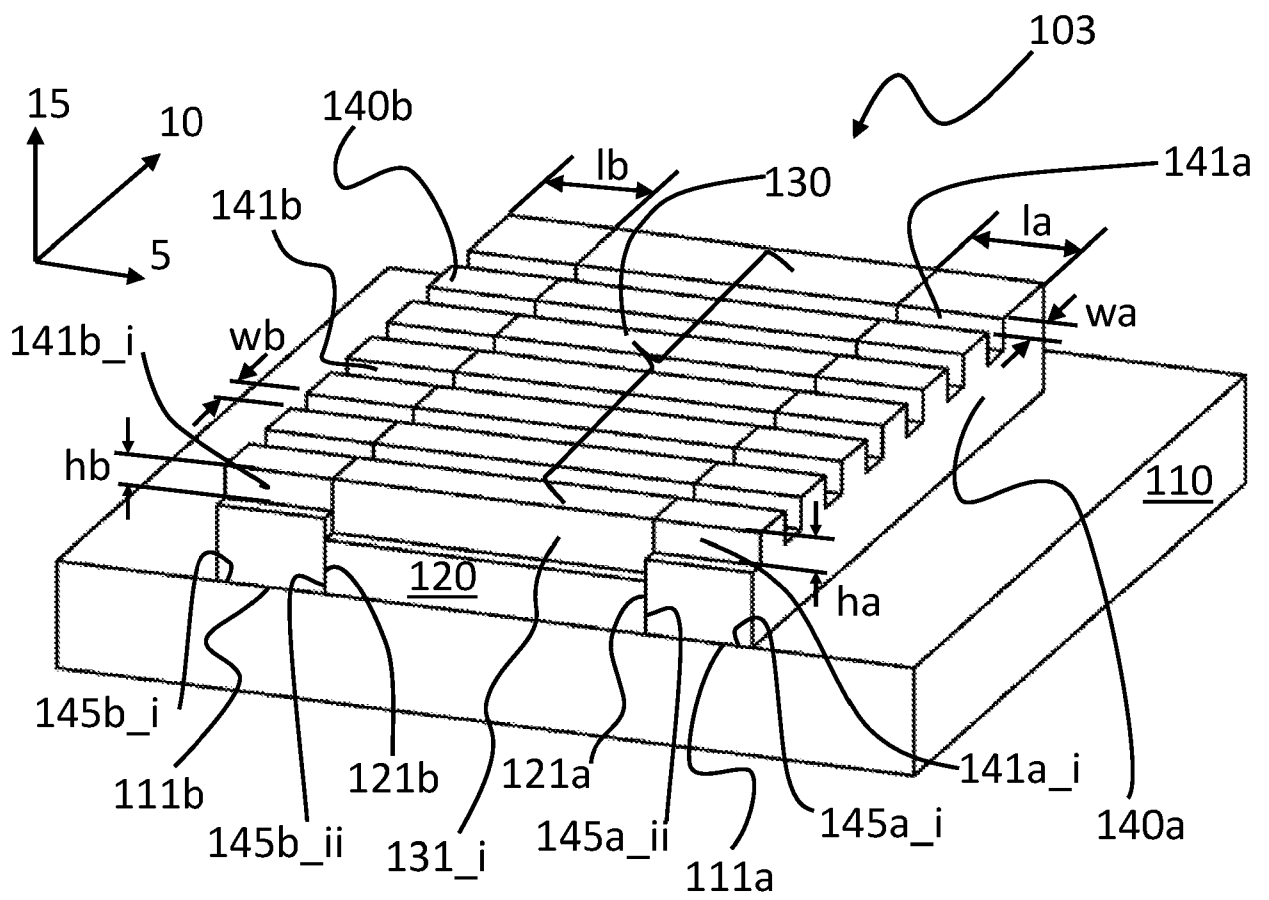


Figure 6

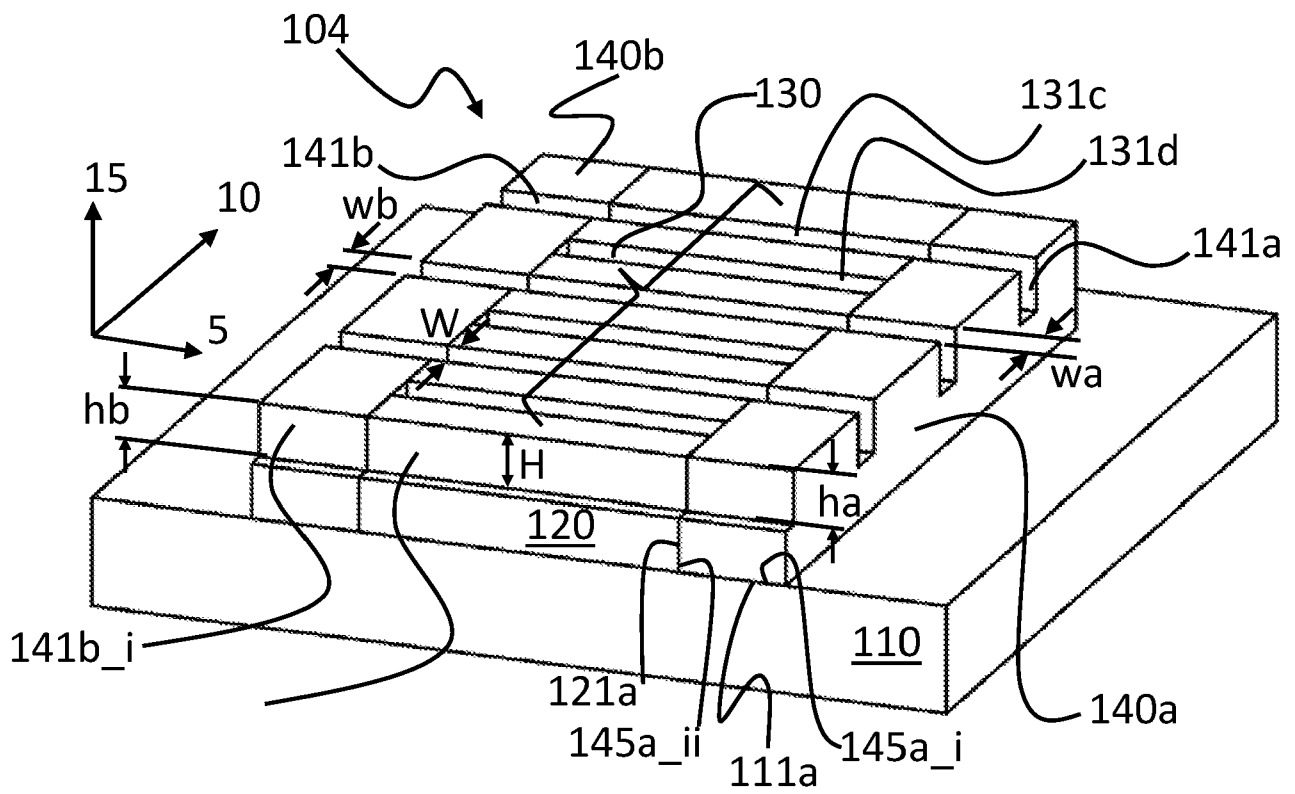


Figure 7

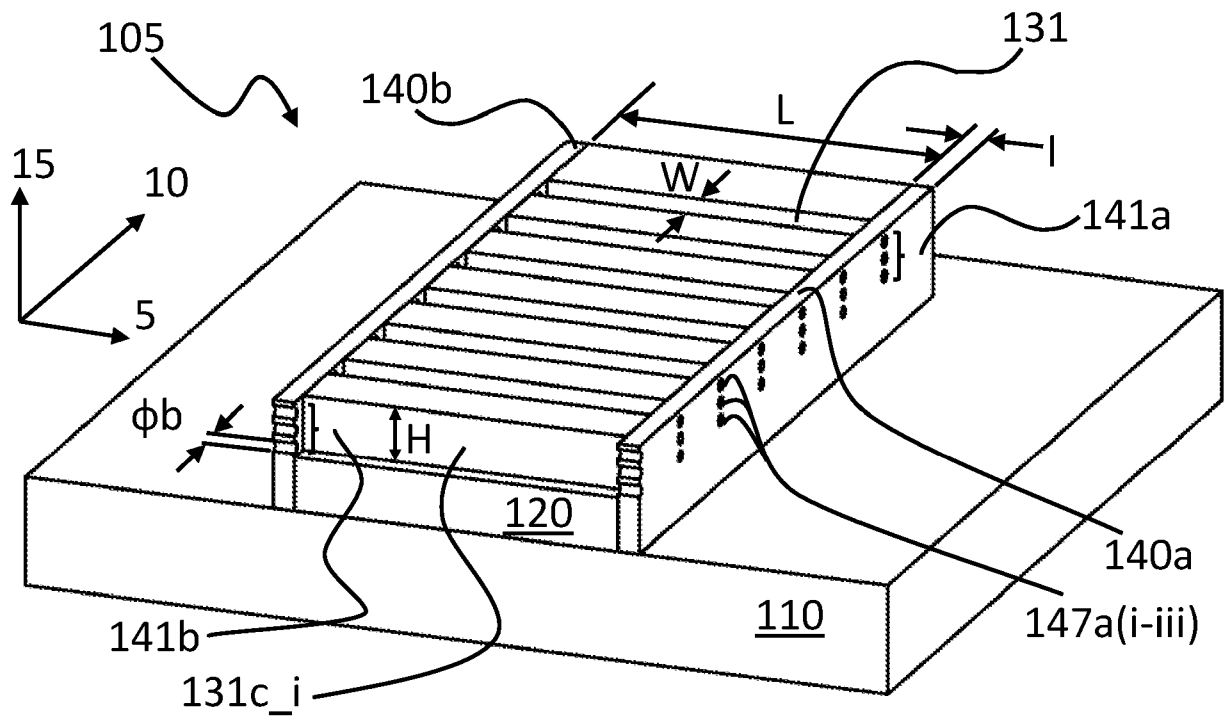


Figure 8

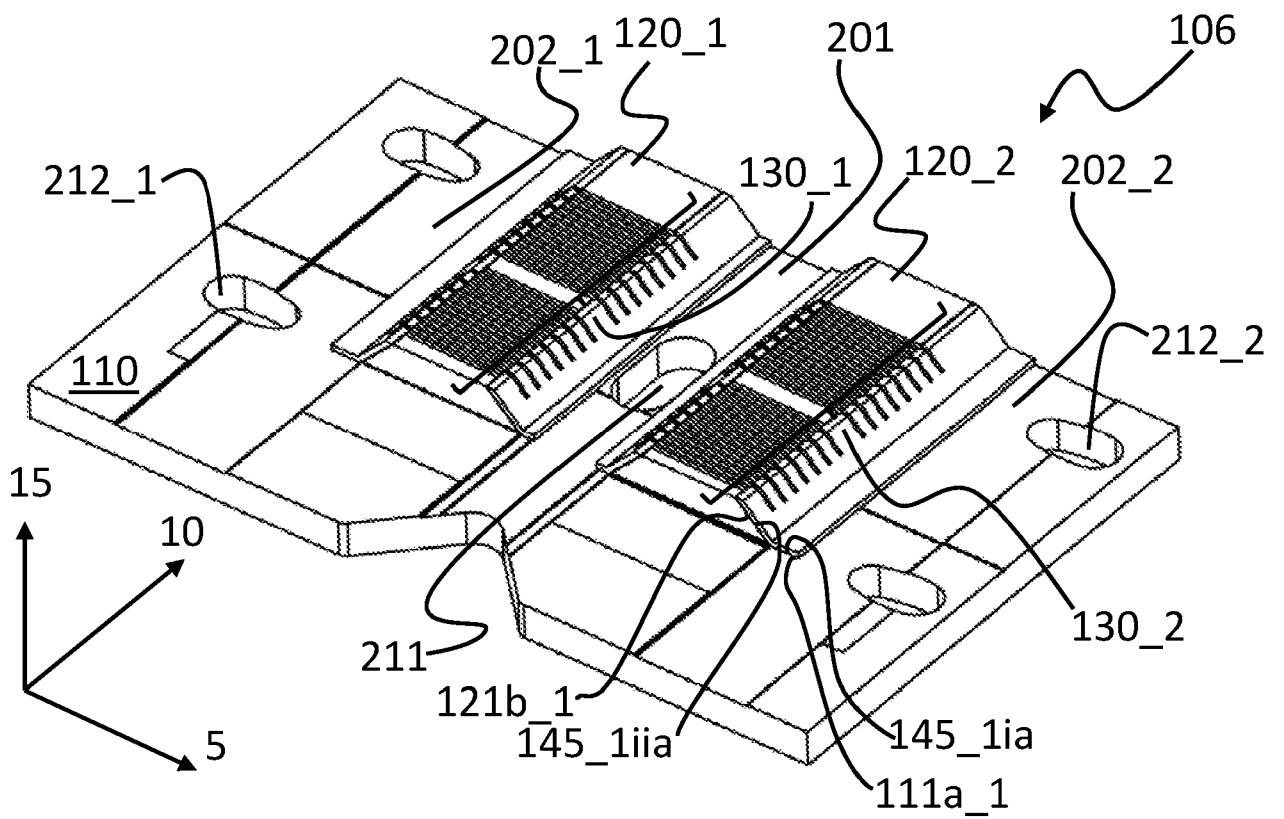
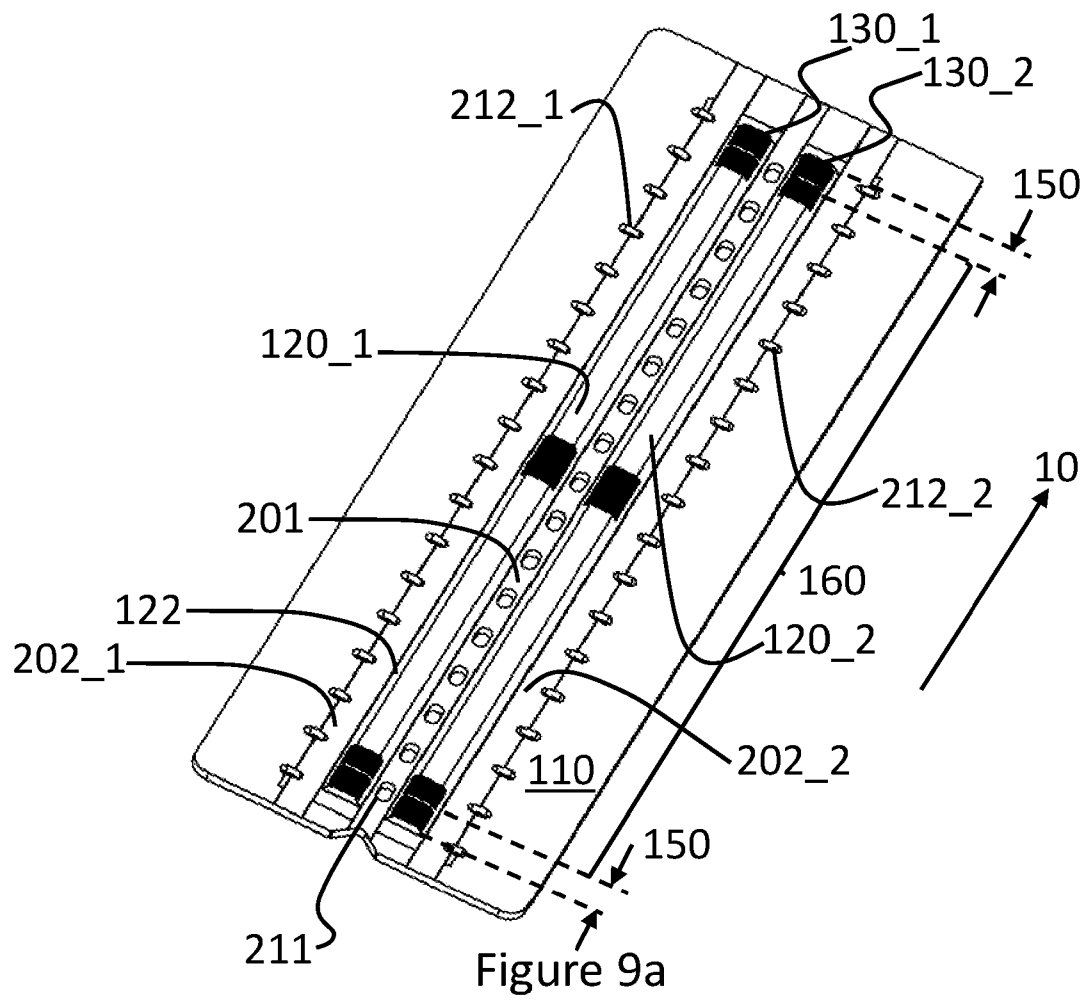


Figure 9b

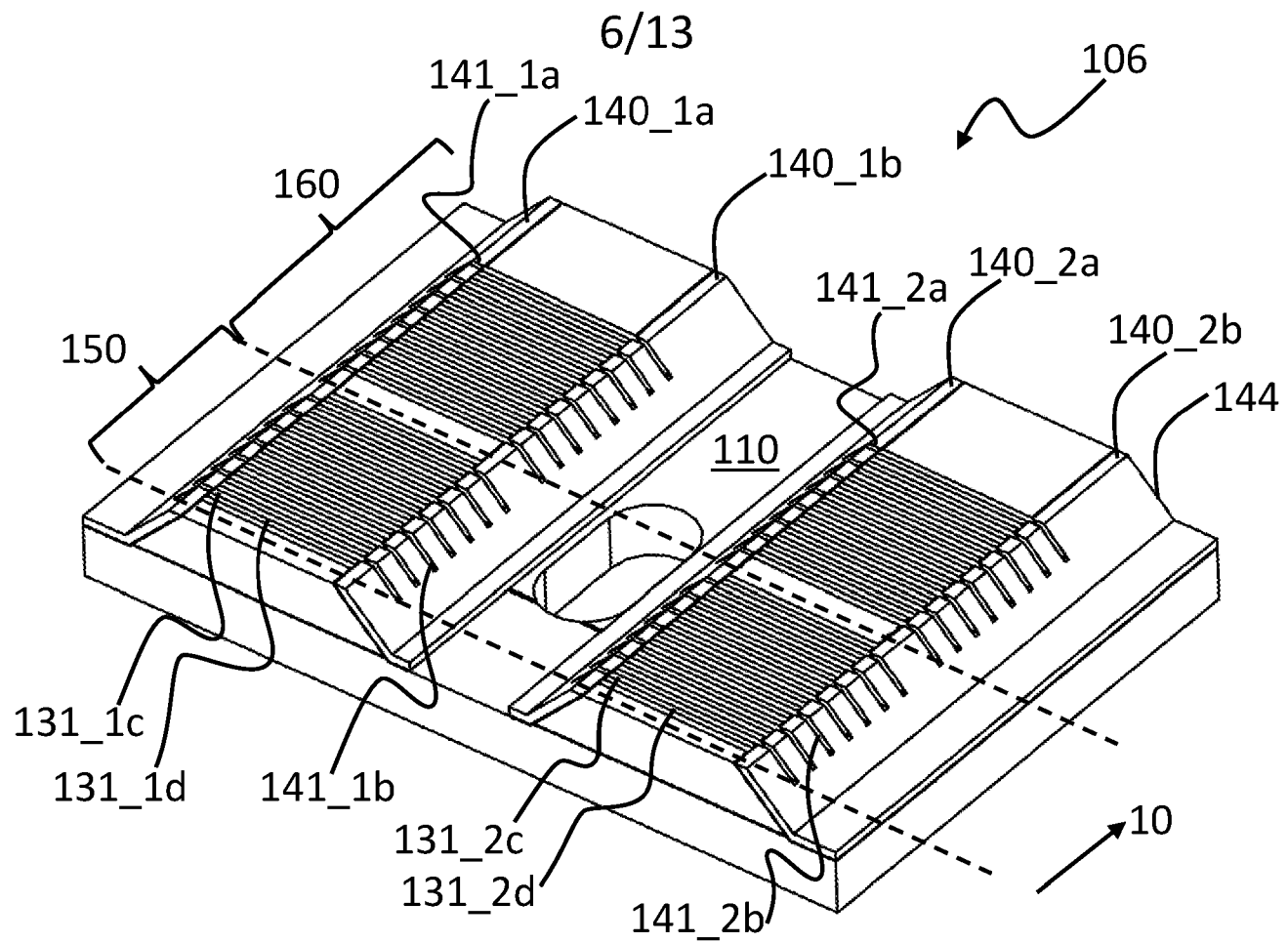


Figure 9c

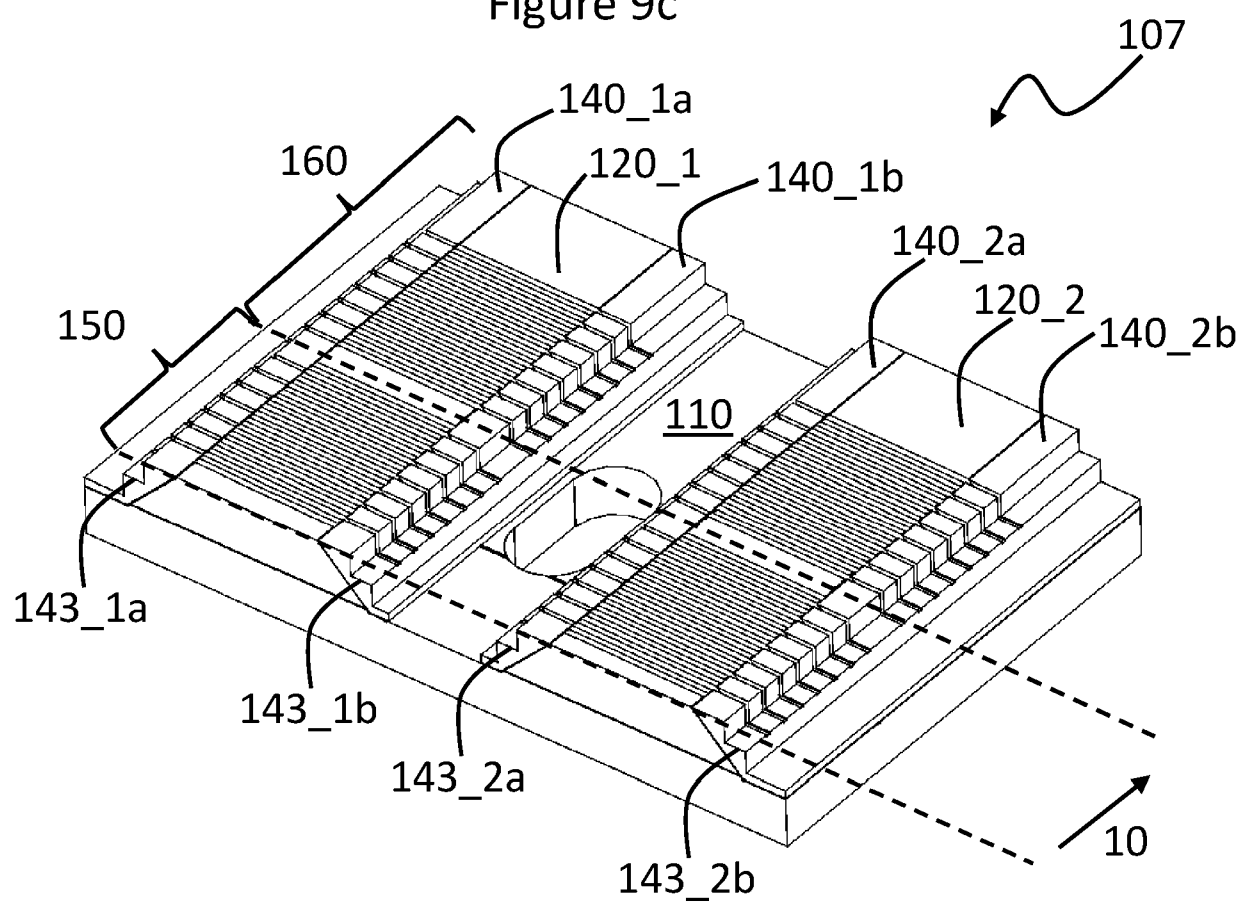


Figure 9d

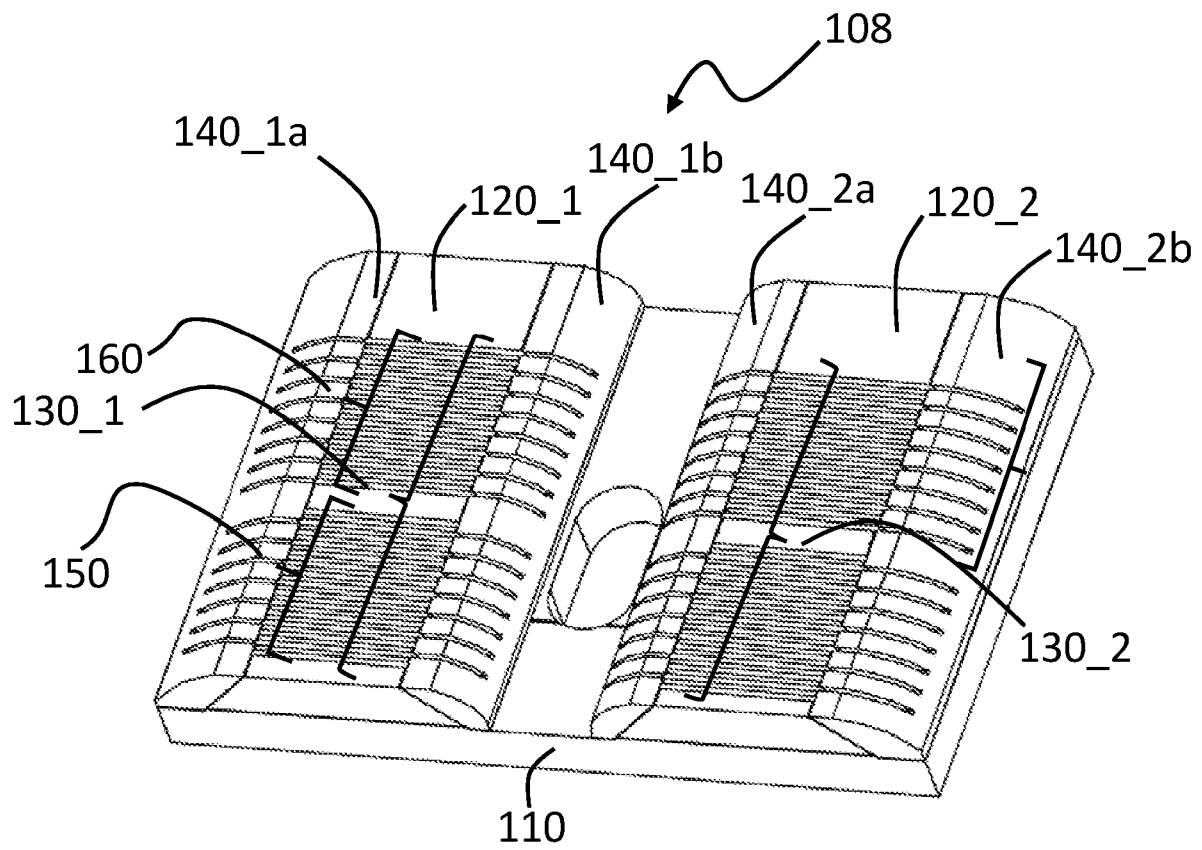


Figure 10a

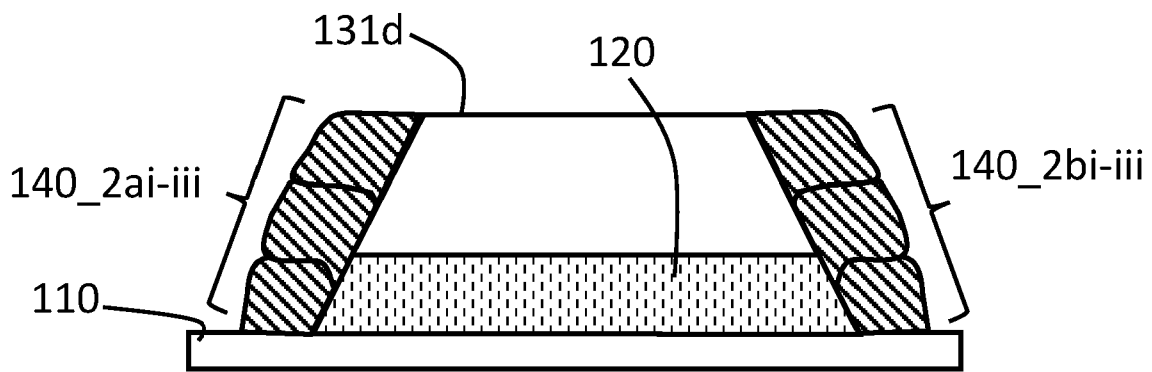


Figure 10b

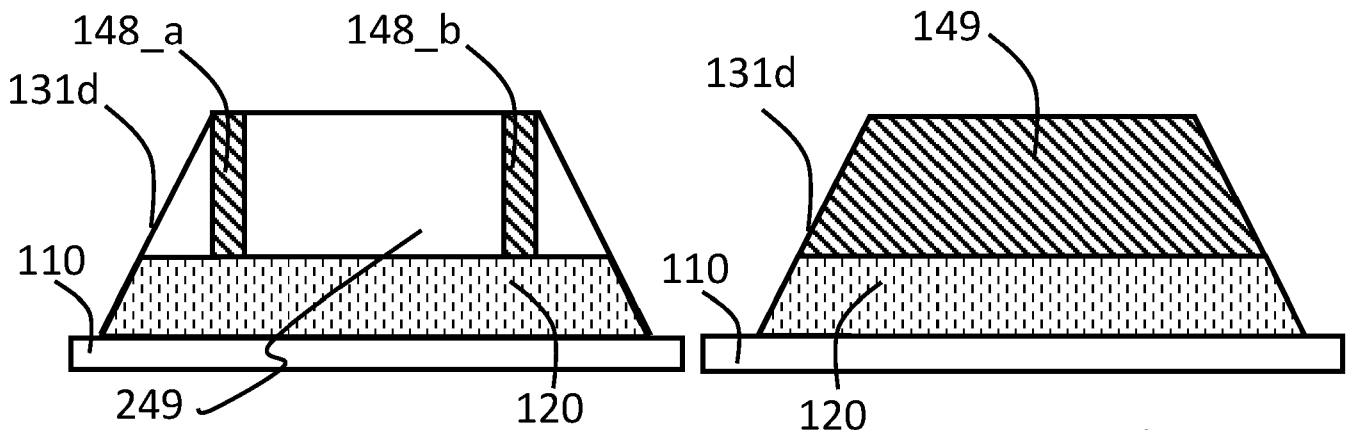


Figure 10c

Figure 10d

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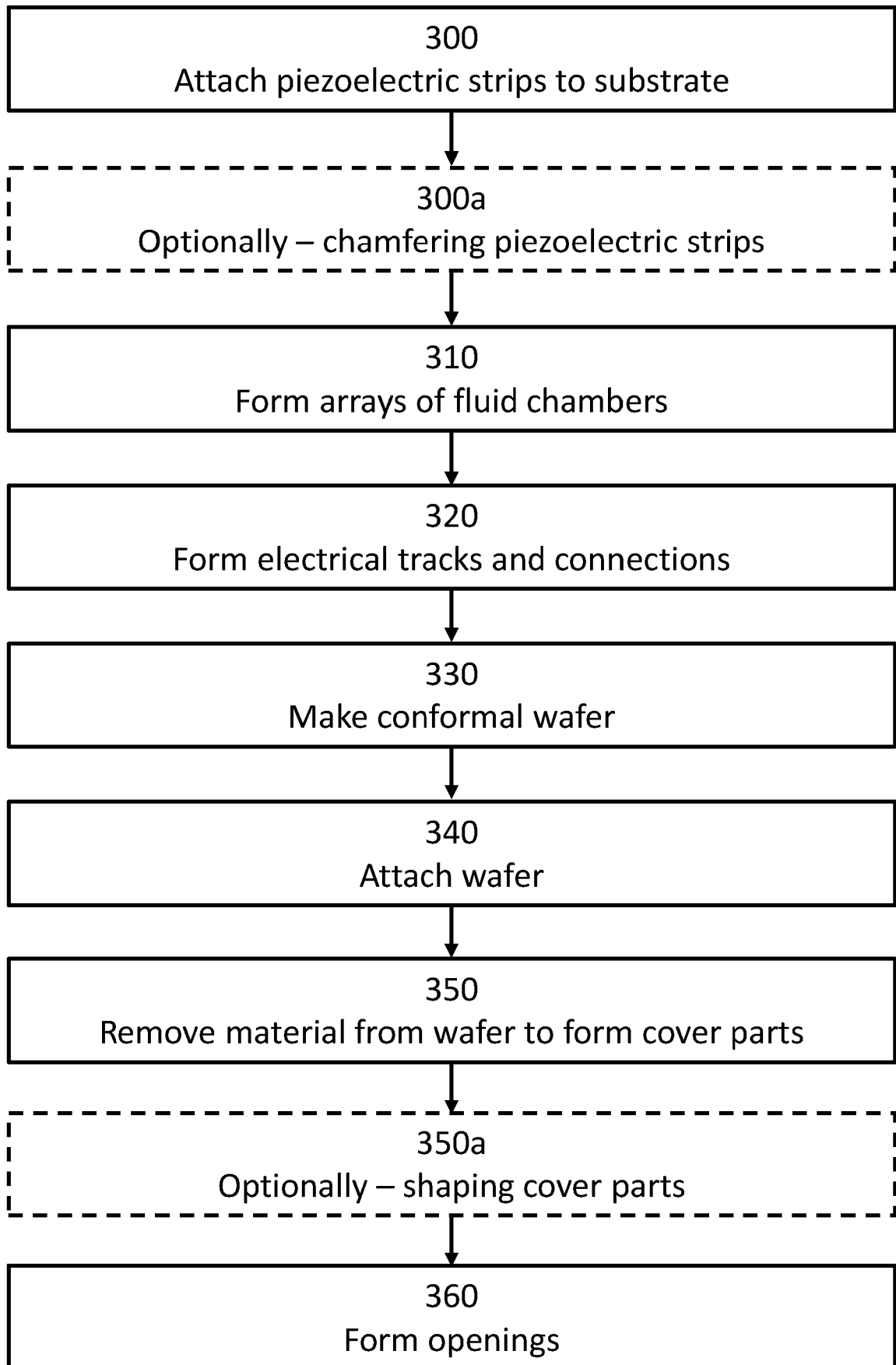


Figure 11a

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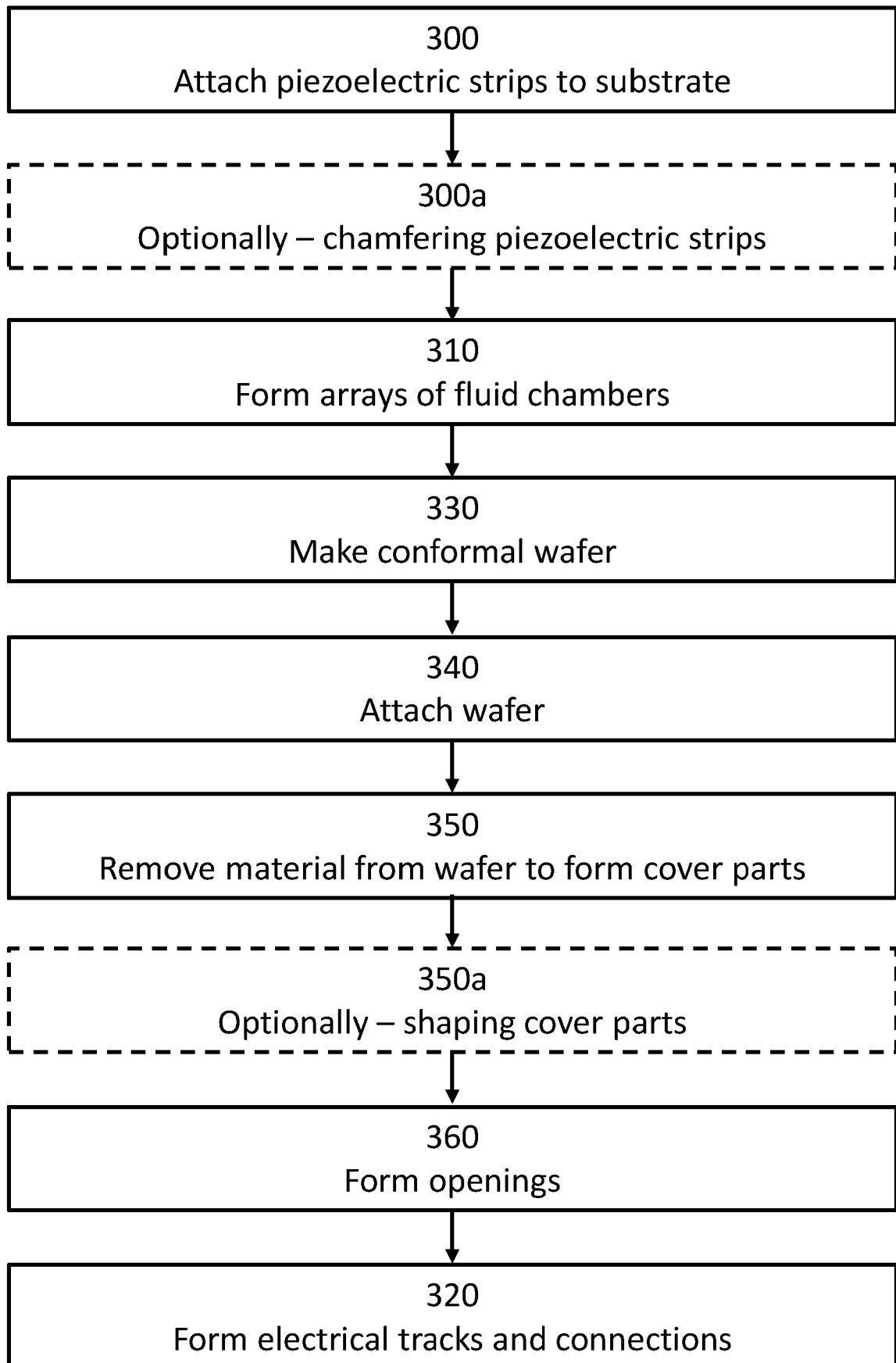


Figure 11b

Figure 12b

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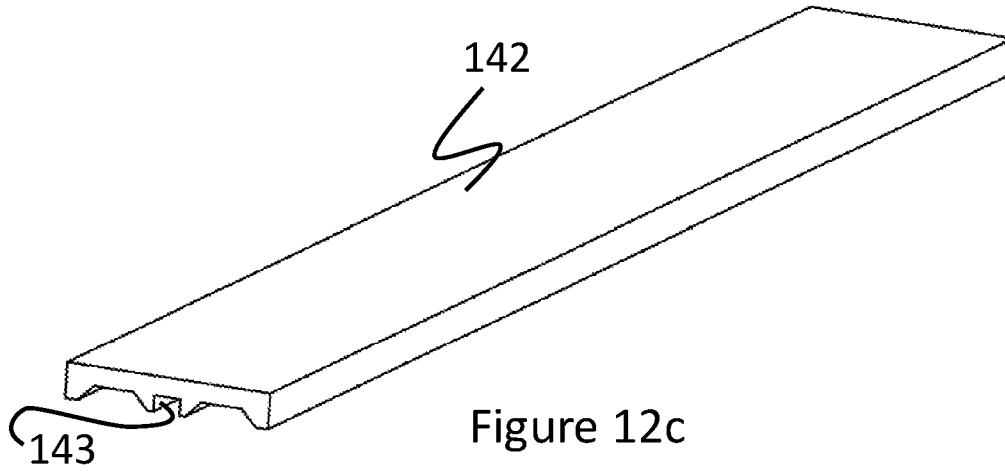


Figure 12c

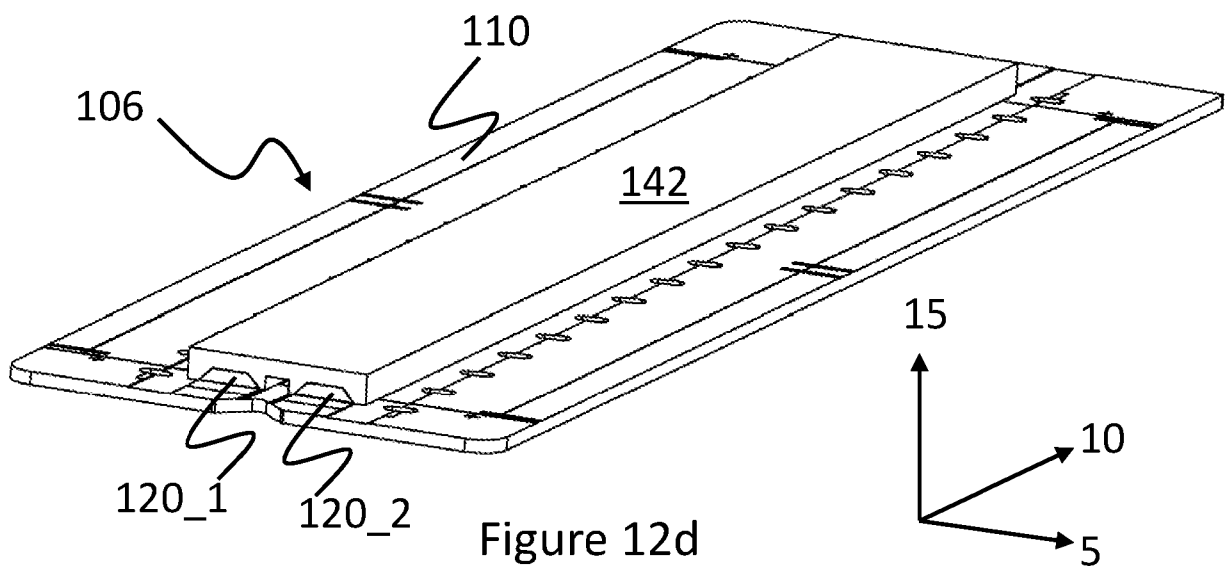


Figure 12d

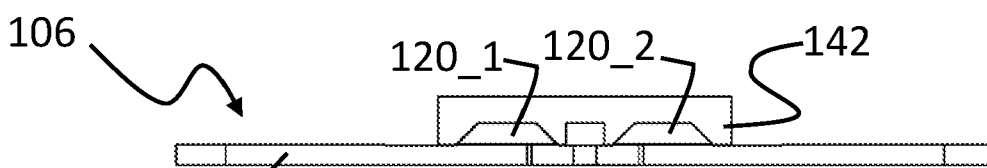


Figure 12e

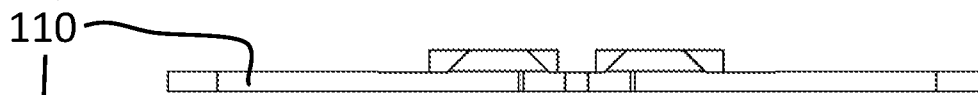


Figure 12f

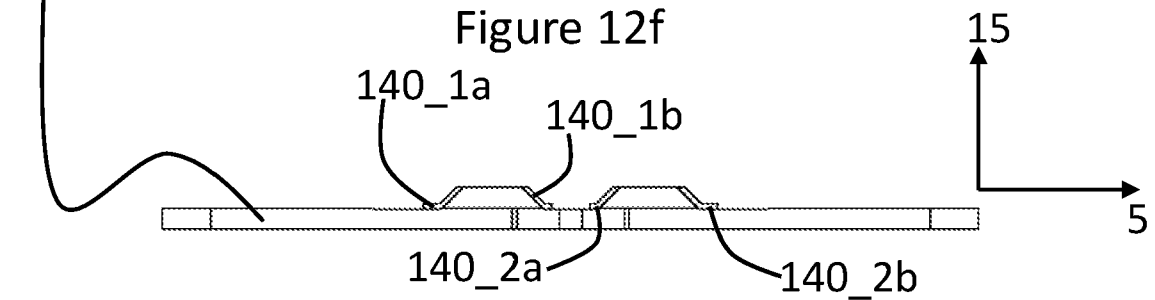


Figure 12g

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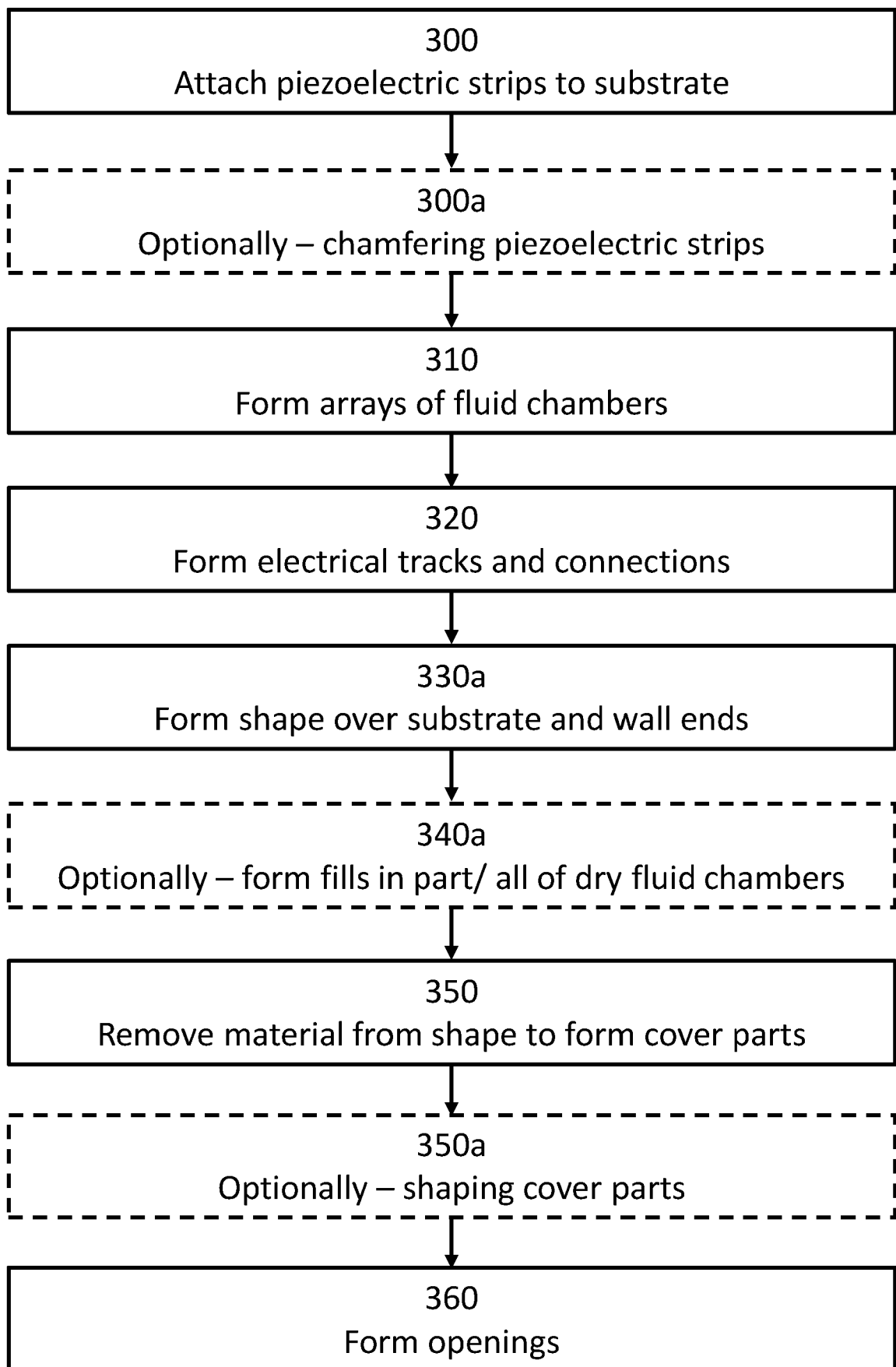


Figure 13a

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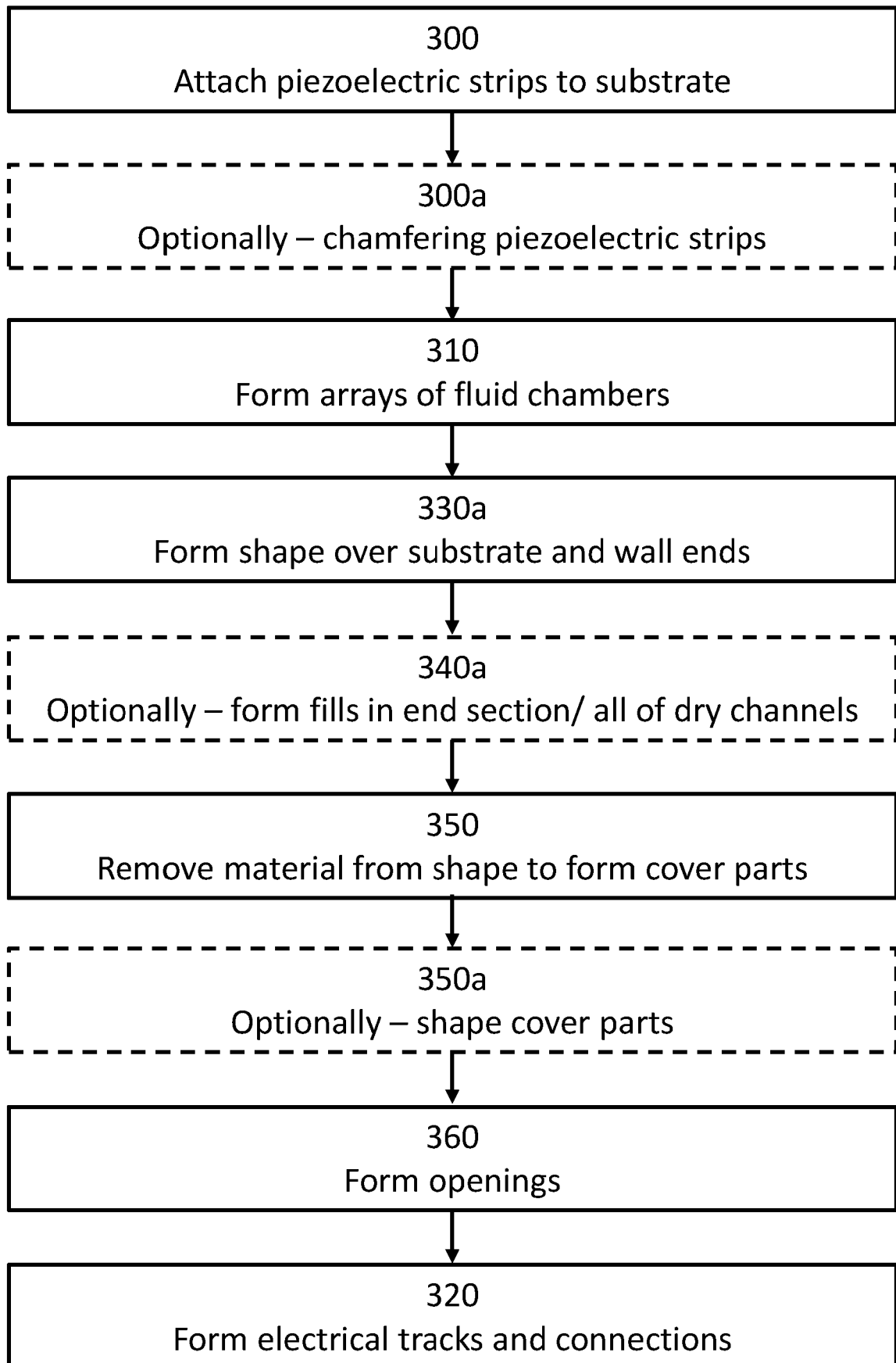


Figure 13b

## **AN ACTUATOR COMPONENT FOR A DROPLET EJECTION HEAD AND METHOD FOR MANUFACTURING THE SAME**

The present disclosure relates to an actuator component for a droplet ejection head and to a  
5 method of manufacturing the actuator component. The actuator component may be particularly suitable for a drop-on-demand ink-jet printhead, or, more generally, a droplet ejection apparatus and, specifically, a droplet ejection apparatus comprising one or more actuator components. The actuator components provide an array of fluid chambers, which each have a piezoelectric actuator element and a nozzle, the piezoelectric actuator element  
10 being operable to cause the release, in an ejection direction, of fluid droplets through the nozzle in response to electrical signals.

### **BACKGROUND**

Droplet ejection heads are now in widespread usage, whether in more traditional  
15 applications, such as inkjet printing, or in 3D printing, or other rapid prototyping techniques. Accordingly, the fluids, e.g. inks, may have novel chemical properties to adhere to new substrates and increase the functionality of the deposited material. Droplet ejection heads have been developed that are capable of use in industrial applications, for example for printing directly onto substrates such as ceramic tiles or textiles or to form elements such as  
20 colour filters in LCD or OLED displays for flat-screen televisions. Such industrial printing techniques using droplet ejection heads allow for short production runs, customization of products and even printing of bespoke designs. It will therefore be appreciated that droplet ejection heads continue to evolve and specialise so as to be suitable for new and/or increasingly challenging applications. However, while a great many developments have  
25 been made in the field of droplet ejection heads, there remains room for improvements.

In recent years, there has been increasing interest in printing at higher frequencies and/or in printing using aqueous or electrically conducting inks and fluids. There is also increased interest in flexible designs such that different types of droplet ejection heads with differing  
30 functionality can be produced from variants on a base actuator component architecture. Such flexibility has benefits for production responsiveness and inventory requirements and hence for cost savings. However, thus far it has proven difficult to make a flexible droplet ejection

head architecture where variants to address different types of fluids or performance requirements can be simply and readily produced.

## SUMMARY

- 5 The present invention allows ready customisation of a single part or limited number of parts so as to produce printhead variants to address different market and customer requirements, such as operating at higher frequencies, or working with aqueous or electrically conducting inks.
- 10 Aspects of the invention are set out in the appended independent claims, while details of particular embodiments of the invention are set out in the appended dependent claims.

According to a first aspect of the disclosure there is provided an actuator component for a droplet ejection head; wherein said actuator component comprises a substrate and one or  
 15 more strips of piezoelectric material fixedly attached to said substrate; wherein said one or more strips of piezoelectric material comprise one or more layers of piezoelectric material, and an array of fluid chambers defined within said one or more strips of piezoelectric material and extending in an array direction; wherein said actuator component further comprises one or more cover parts; wherein the or each cover part extends in said array  
 20 direction and is fixedly attached to at least one of a side face of one of said strips of piezoelectric material and/or at least a portion of said substrate ; and wherein said one or more cover parts comprise a plurality of openings so as to enable fluid to be supplied to selected ones of said fluid chambers through said openings.

- 25 According to certain embodiments the openings provide for an ALA (Alternate Line Active) design.

According to certain other embodiments there is provided a design where the openings provide for flow restrictors.

30

According to certain other embodiments there is provided a design where the openings provide for both an ALA design and for flow restrictors.

According to certain other embodiments there is provided a design where the array of fluid chambers comprises a main region and also comprises a buffer region at either or both ends of the array of fluid chambers, wherein the openings and/or the fluid chambers in the buffer region(s) differ from those in the main region.

According to a second aspect of the disclosure there is provided a method of manufacturing an actuator component for a droplet ejection head, wherein said method comprises the steps of:

- fixedly attaching one or more strips of piezoelectric material to a substrate;
- forming one or more arrays of fluid chambers in said one or more strips of piezoelectric material;
- forming a wafer that is conformal to said one or more strips of piezoelectric material and said substrate, wherein said wafer comprises one or more parts;
- fixedly attaching at least a part of said wafer to said substrate and at least a part of said wafer to said one or more strips of piezoelectric material;
- removing material from said wafer and thereby forming one or more cover parts which are fixedly attached to a face of one of said strips of piezoelectric material and at least a portion of said substrate; and
- selectively forming a plurality of openings in said cover parts so as to enable fluid to be supplied to selected ones of said fluid chambers through said openings.

According to a third aspect of the disclosure there is provided a method of manufacturing an actuator component for a droplet ejection head, wherein said method comprises the steps of:

- fixedly attaching one or more strips of piezoelectric material to a substrate;
- forming one or more arrays of fluid chambers in said one or more strips of piezoelectric material;
- forming a shape over said substrate and at least a part of said one or more strips of piezoelectric material;

removing material from said shape and thereby forming one or more cover parts which are fixedly attached to a face of one of said strips of piezoelectric material and/or to at least a portion of said substrate; and

- selectively forming a plurality of openings in said cover parts so as to enable fluid to  
 5 be supplied to selected ones of said fluid chambers through said openings.

According to a fourth aspect of the disclosure there is provided a droplet ejection head comprising an actuator component according to the first aspect of the disclosure and manufactured according to the second or third aspects of the disclosure.

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### **BRIEF DESCRIPTION OF THE DRAWINGS**

Figure 1 depicts an actuator component according to an embodiment comprising a cover part to one side of a strip of piezoelectric material, wherein the cover part comprises openings that are narrower than the fluid chambers;

- 15 Figure 2a is a detailed view of a fluid chamber and an opening, such as those of Figure 1;  
 Figure 2b is a detailed view of a fluid chamber and an opening, similar to that of Figure 2a but where the fluid chamber comprises coating layers;  
 Figure 2c is a cross-sectional view of part of the actuator component of Figure 1, along A-A;

- 20 Figure 2d is a cross-sectional view corresponding to that of Figure 2c, but at a later point in the production of the actuator component;

Figure 3 depicts an actuator component according to Figure 1, further comprising ports and boundary sections and indicating the fluid paths through the actuator component when installed in a droplet ejection head;

- 25 Figure 4 shows a part of a droplet ejection head comprising an actuator component according to Figure 3 and further comprising a cover wafer;

Figure 5 shows an actuator component according to another embodiment comprising a cover part on one side of a strip of piezoelectric material, wherein the cover part comprises openings that are shallower than the fluid chambers;

- 30 Figure 6 depicts an actuator component according to another embodiment comprising cover parts on both sides of a strip of piezoelectric material, wherein said cover parts comprise openings that are narrower than the fluid chambers;

Figure 7 depicts an actuator component according to another embodiment comprising a respective cover part on each side of a strip of piezoelectric material, wherein the cover parts provide openings to alternate fluid chambers;

Figure 8 depicts an actuator component according to another embodiment, where the openings in the cover parts comprise multiple sub-openings per fluid chamber;

Figure 9a depicts an actuator component comprising two strips of piezoelectric material prior to attaching the cover parts;

Figures 9b and 9c show details of the actuator component of Figure 9a with cover parts attached, on both sides of each strip of piezoelectric material;

Figure 9d depicts a variant of the actuator component of Figures 9b and 9c with a cover part that has additional shaping;

Figure 10a depicts an actuator component according to another arrangement where the cover parts comprise a material built up in layers;

Figure 10b depicts a cross-section of a fluid chamber of the actuator component of Figure 10a detailing the layers of material;

Figure 10c depicts a cross-section of a fluid chamber similar to that of Figure 10b, but wherein the cover parts comprise a pillar inside the fluid chamber;

Figure 10d depicts a cross-section of a fluid chamber similar to that of Figure 10b, but wherein the cover parts comprise filling that fills the fluid chamber;

Figure 11a is a flow chart showing steps in the manufacture of an actuator component;

Figure 11b is an alternative flow chart depicting steps in the manufacture of an actuator component;

Figure 12a depicts a process step in the manufacture of an actuator component according to the embodiment of Figures 10a-10d;

Figure 12b depicts a further process step from that of Figure 12a, where the two strips of piezoelectric material are chamfered to give a trapezoidal profile and arrays of fluid chambers are formed in the strips of piezoelectric material;

Figure 12c depicts a wafer for attaching to the actuator component of Figure 12b;

Figure 12d depicts the wafer of Figure 12c attached to the actuator component of Figure 12b;

Figure 12e depicts a cross-section of the actuator component of Figure 12d;

Figure 12f depicts a cross-section of the actuator component of Figure 12e with material removed the wafer to form cover parts on both sides of the strips of piezoelectric material; Figure 12g depicts a further cross-section of the actuator component of Figure 12f with a chamfer formed in the cover parts;

5 Figure 13a is a flow chart showing steps in an alternative method of manufacture of an actuator component; and

Figure 13b is an alternative flow chart to that of Figure 13a depicting steps in the manufacture of an actuator component.

10 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 OF THE DRAWINGS**

Embodiments and their various implementations will now be described with reference to the  
15 drawings. Throughout the following description, like reference numerals are used for like elements where appropriate.

Figure 1 depicts an actuator component 101 according to an embodiment comprising a cover part 140 to one side of a piezoelectric strip 120. In more detail, Figure 1 depicts an actuator  
20 component 101 for a droplet ejection head; where the actuator component 101 comprises a substrate 110 and a strip of piezoelectric material 120, or a plurality of such strips of piezoelectric material, fixedly attached to the substrate 110. It should be understood that in this and all embodiments described herein, the or each strip of piezoelectric material 120 may comprise a single layer of piezoelectric material or more than one layer of piezoelectric  
25 material; for example it may comprise a laminate comprising layers of piezoelectric material fixedly attached together. Any suitable method of fixing such layers of piezoelectric material together may be utilised. The substrate material 110 may also be made from a piezoelectric material, or alternatively any other suitable material may be used.

30 The strip of piezoelectric material 120 further comprises an array 130 of fluid chambers defined within the strip of piezoelectric material 120 and extending in an array direction 10. The array 130 of fluid chambers comprises a plurality of fluid chambers 131. The fluid

chambers (131\_i-131\_n) extend side-by-side in the array direction 10 from a respective first longitudinal end to a respective second, opposite longitudinal end of the array 130 of fluid chambers; said array direction 10 being generally perpendicular to a fluid chamber height direction 15. Each fluid chamber 131 is elongate in a fluid chamber extension direction 5 which is at an angle to the array direction 10, and each fluid chamber 131 forms an open channel in the strip of piezoelectric material 120 (open in the fluid chamber height direction 15 and open at either end in the fluid chamber extension direction 5). To enable the internal geometry of the fluid chambers 131 to be more readily visualised, the first fluid chamber (131\_i) is shown with one side removed in Figure 1 (and likewise in Figures 3-8).

In this implementation, the array direction 10 is perpendicular to the fluid chamber extension direction 5, but it should be understood that this is by no means essential and in other implementations the strip of piezoelectric material 120 may be aligned at an angle other than 90° on the substrate 110. The fluid chambers 131 extend side-by-side such that they are parallel to each other in the array direction 10; such an arrangement may allow for close-packing of fluid chambers 131, but this is by no means essential and other arrangements may be envisaged. The fluid chambers 131 have a length L in the fluid chamber extension direction 5, a width W in the array direction 10 and a height H in a fluid chamber height direction 15, and a cross-sectional area  $A_c = H * W$  (see Figure 2a).

Considering Figure 1 further, it can be seen that the actuator component 101 further comprises at least one cover part 140 which extends in the array direction 10, adjacent to the strip of piezoelectric material 120. The or each cover part 140 is fixedly attached to at least one of a side face 121a of the strip of piezoelectric material 120 and/or to at least a portion 111 of the substrate 110. It should be understood that in some arrangements the, or each, cover part may be fixedly attached as in the arrangement of Figure 1, where the cover part 140 comprises two inner faces 145\_i, 145\_ii which are fixedly attached to the portion 111 and the side face 121a respectively. The cover part 140 may be made of the same material as the strips of piezoelectric material 120, but this is by no means essential and other materials may be used.

The, or each, cover part 140 further comprises a plurality of openings 141 (141<sub>i</sub>-141<sub>n</sub>) so as to enable fluid to be supplied to selected ones of the fluid chambers 131 through the openings 141. As for the first fluid chamber 131<sub>i</sub>, the corresponding first opening 141<sub>i</sub> is shown with one side removed so that the interior of the opening 141<sub>i</sub> is visible. In this implementation the actuator component 101 comprises at least one opening 141 per strip of piezoelectric material 120 for each fluid chamber 131. Thus, in this implementation, in use, fluid may flow into and through the openings 141 and then through the fluid chambers 131. As can be seen from Figure 1, and in detail from Figure 2a, which details a portion of a fluid chamber 131 and an opening 141, in this implementation the openings 141 have the same height,  $h$ , as the height  $H$  of the fluid chambers 131 in the fluid chamber height direction 15, but are narrower than them in the array direction 10. As can also be seen in Figure 1, the openings 141 are shorter than the fluid chambers 131 in the fluid chamber extension direction 5. The openings 141 therefore have a height  $h$ , where  $h=H$ , a width  $w$ , where  $w<W$ , and a length  $l$ , where  $l<L$ ; and have a cross-sectional area  $A_o=h*w$ , where  $A_o<A_c$ .

Figures 2a and 2b depict a portion of a fluid chamber 131 and a portion of an opening 141, such as those of Figure 1. Figures 2c and 2d depict a portion of a strip of piezoelectric material 120 and substrate 110 along a typical cross-section, such as the location A-A indicated in Figure 1, at different stages in the construction of the actuator component 101.

As detailed in Figure 2b, the fluid chambers 131 may comprise one or more layers  $c1$ - $c_n$  (for example layers  $c1$  and  $c2$  of Figure 2b) deposited on some or all of their internal surfaces, such as a metallic layer or layers to enable actuation of the piezoelectric material, and a protective coating layer or layers to prevent fluids such as inks from causing damage (e.g. corrosion) to the metallic layer(s) and/or to passivate the electronics. Therefore the actuator component 101 comprises electrical tracks and connections. As shown in Figure 2c it should be understood that the metal layer(s) (in this instance a single layer  $c1$ , but this is not limiting) may extend over the outer surfaces of the substrate 110 and the strips of piezoelectric material 120.

Such layer(s) may be deposited as continuous layers, built up one at a time, over some or all of the external surfaces of the actuator component 101, such as on the substrate 110 and the strip(s) of piezoelectric material 120, using any suitable method; such as electroless plating

or metal sputtering/ evaporation. Cutting or other removal techniques may then be used to remove some of the metal layer or layers so as to form electrically isolated electrical tracks and connections. The cover part(s) 140 may then be fixedly attached to the strip of piezoelectric material 120 and the substrate 110 such that at least a portion of the electrical tracks and connections are located between the substrate and the cover part and/or between the strips of piezoelectric material and the cover part. Additional protective layers may be deposited on top of the metal layer(s), prior to attaching the cover part(s) 140, and thereby the actuator component 101 further comprises one or more coating layers c, wherein said coating layers c are located at least in part between the substrate 110 and the cover part 140 and/or between the strips of piezoelectric material 120 and the cover part 140 so as to protect the electrical tracks and connections. Grinding or other removal techniques may be used at a later stage to remove a portion of the layer(s) c<sub>1</sub>-c<sub>n</sub> and, if necessary, some of the top of the cover part 140, as shown in Figure 2d for a single layer c<sub>1</sub>. In such an arrangement, the cover part 140 and the attachment means joining it to the substrate 110 and/or the strip of piezoelectric material 120, may provide additional physical protection and electrical isolation to the electrical tracks and connections.

It may further be understood that in some implementations (not shown) some or all of any metallic layer(s) and/or coating or passivation layer(s) c<sub>1</sub>, c<sub>2</sub> .... c<sub>n</sub> may be deposited at some point after both the fluid chambers 131 and the openings 141 have been formed, such that both the fluid chambers 131 and the openings 141 comprise layer(s) on some or all of their internal surfaces and the substrate 110, and the strip of piezoelectric material 120 and the cover part(s) 140 comprise layer(s) on some or all of their external surfaces. Still further some layer(s) c may be provided to just the fluid chambers 131 and the strip of piezoelectric material 120 and some layers c<sub>both</sub> (not shown) may be provided to both the fluid chambers 131 and the openings 141, and possibly also to the cover part(s) 140, depending on when in the manufacturing process they are provided and by what method. In these cases, it should be understood that the cross-sectional areas A<sub>c</sub> of the fluid chambers 131 and/or the cross-sectional areas A<sub>o</sub> of the openings 141 will be reduced by any layer(s) that are provided thereto, and that it is the final open areas through which fluid may pass that are of importance when considering the relationships between the cross-sectional areas A<sub>c</sub> and A<sub>o</sub> of the fluid chambers 131 and the openings 141 respectively (see Figure 2b). It should be

understood that, where such metallic and protective layers  $c$  and/or  $c_{\text{both}}$  are present, the width  $W$ , and the height  $H$  of the fluid chambers 131 referred to herein (and the width  $w$  and height  $h$  of the openings 141, when the openings also comprise coatings) are the width  $W, w$  and height  $H, h$  of the open cross-sectional areas  $A_c (=H*W)$  and  $A_o (=h*w)$ .

5

Figure 3 depicts an actuator component 101 according to Figure 1 further comprising an inlet port 211, an inlet manifold channel 201, an outlet manifold channel 202 and an outlet port 212. As can be seen from Figure 3 the actuator component comprises a boundary section 230 on either side of the substrate 110 so that the actuator component 101 comprises one or more manifold channels 201, 202 adjacent to the strip of piezoelectric material 120, wherein each of said one or more manifold channels 201, 202 is fluidically connected to a respective port 211, 212 and, in this arrangement, bounded on their outer edges by the boundary section 230. However, it should be understood that this configuration is by no means essential and that other arrangements and ways of forming the manifold channels 201, 202 may be envisaged in order to supply fluid to the array 130 of fluid chambers. Further, it should be understood that where there are multiple strips of piezoelectric material 120, such that a droplet ejection head comprises multiple arrays 130 of fluid chambers, then the boundaries 230 may contain openings therein to allow fluid to flow between neighbouring manifold channels and hence between neighbouring strips of piezoelectric material 120. Alternatively, configurations where adjacent strips of piezoelectric material 120 share manifold channels may be envisaged. In some implementations, boundaries 230 may be located on the outer boundary of the actuator component 101, or at chosen locations within the actuator component 101 as appropriate, for example if required to separate inlet manifold channels 201 and outlet manifold channels 202, and/or to provide additional structural integrity to the actuator component.

25

Turning now to Figure 4, this depicts a part of a droplet ejection head 20 comprising the actuator component 101 of Figure 3 (which has been inverted), and further comprising a nozzle wafer 220 fixedly attached thereto. The nozzle wafer 220 acts to fluidically seal the array 130 of fluid chambers (largely not visible in this view), the openings 141, the manifold channels 201, 202 and the boundary section 230 in the fluid chamber height direction 15.

30

Nozzles 221 may be formed in the nozzle wafer 220 so that each fluid chamber 131 further comprises one or more nozzles 221.

It should be understood that Figure 4 is a cross-section through the droplet ejection head 20 and that the boundary section 230 may be formed so as to seal the manifold channels 201, 202 at their longitudinal ends in the array direction 10 or, alternatively, the droplet ejection head 20 may comprise further parts to fluidically seal the ends of the manifold channels 201, 202 in the array direction 10. Therefore, when the actuator component 101 is assembled into a droplet ejection head 20 the fluid chambers 131 are fluidically connected at one end to the inlet manifold channel 201 via the openings 141, and at the other end the fluid chambers 131 are fluidically connected to the outlet manifold channel 202. In this implementation the inlet manifold channel 201 is fluidically connected to an inlet (not shown) via the inlet port 211 and further fluid paths (also not shown), and the outlet manifold channel 202 is fluidically connected to an outlet (not shown) via the outlet port 212 and further fluid paths (also not shown).

During use of the arrangement of Figure 4, there is a fluid flow from the inlet port 211 into and along the inlet manifold channel 201, into and through each opening 141 and then into and through each fluid chamber 131 in the array 130 of fluid chambers, out of the fluid chambers and into and along the outlet manifold channel 202, and then into the outlet port 212 (generally this arrangement is referred to as a through-flow design). In an alternative arrangement, the actuator component 101 may be assembled into a droplet ejection head 20 which may be arranged to be supplied in gravity mode; in this arrangement both ports 211 and 212 operate as inlet ports, and it should be understood that hence both manifold channels 201, 202 operate as inlet manifold channels so as to supply fluid to both ends of the fluid chambers 131, via the opening(s) 141 on one or both sides of the strip of piezoelectric material 120.

The fluid chambers 131 each comprise one or more piezoelectric actuator elements. The piezoelectric actuator elements are operable to cause the ejection of a fluid droplet D through a nozzle 221 in an ejection direction 30 in response to electrical signals. The ejection direction 30 is generally perpendicular to the array direction 10 and parallel to the chamber

height direction 15, as shown in Figure 4 where a droplet D<sub>i</sub> has been ejected from fluid chamber 131<sub>i</sub>.

It should be understood that in the implementation shown in Figure 4 the openings 141 act  
 5 as restrictors, to choke or throttle the fluid flow through the fluid chambers 131 and to attenuate acoustic borne pressure fluctuations and their associated acoustic velocity field disturbances, so as to reduce cross-talk effects between fluid chambers 131 in the array 130 of fluid chambers and thereby enable the droplet ejection head 20 to operate at higher frequencies. Crosstalk is observed in practice as (a) variation in a channel's jetting  
 10 performance based on the duty cycle of adjacent or near-neighbour channels, and (b) unwanted ejection events in extreme cases. Direct crosstalk effects originate from wall deflections in active channels deforming adjacent channels. Finally, fluidic crosstalk results from pressure waves radiated from the fluid chamber and into the manifold channel(s), and then into surrounding fluid chambers 131 via the fluid path. The addition of restrictor(s) may  
 15 reduce the fluidic crosstalk and additionally improve drop velocity and volume correlation and therefore the trimming.

It can be seen from Figure 4 that the nozzle 221<sub>i</sub> is located at the centre of the fluid chamber 131<sub>i</sub> in the fluid chamber extension direction 5, with the other nozzles similarly located,  
 20 but this is by no means limiting and in other implementations the average position of the nozzles may be closer to one or other end of the fluid chamber 131 in the fluid chamber extension direction 5, depending on the fluidic and acoustic performance of the droplet ejection head 20. It may further be understood that whilst Figure 4 comprises a row of nozzles which are all aligned at the same position in the fluid chamber extension direction  
 25 5, this is by no means essential, and in other implementations the nozzle row may comprise nozzles at staggered positions relative to each other.

Turning now to Figure 5, this discloses an actuator component 102 according to another embodiment, which is very similar to the actuator component 101 of Figure 1, therefore like  
 30 references are used as appropriate. The actuator component 102 comprises a cover part 140 with a plurality of openings 141 that are shallower than the fluid chambers 131 (unlike the actuator component 101 depicted in Figure 1, where the openings 141 are narrower than the

fluid chambers 131). Therefore, the plurality of openings 141 of actuator component 102 have a height  $h < H$ , and a width  $w = W$ . In this arrangement the openings 141 also have a length  $l$  and the fluid chambers 131 have a length  $L$ , both the same as for Figure 1, where  $l < L$ . The actuator component 102 could be used in place of the actuator component 101 in the part of the droplet ejection head 20 of Figure 4, where the openings 141 act as restrictors to the fluid chambers 131.

It should be understood that in some alternative arrangements (not shown), rather than placing the plurality of openings 141 on a first side 121a of the array 130 of fluid chambers, they may be placed on a second side 121b instead, such that when the actuator component 101, 102 is implemented in a droplet ejection head 20, as in Figure 4, the plurality of openings 141 would connect the array 130 of fluid chambers to the outlet manifold channel 202 and act to restrict the fluid flow leaving the fluid chambers 131. Thus in such an alternative arrangement, in use, fluid may flow into and through the fluid chambers 131, and then into and through the openings 141.

Considering now Figure 6, it can be seen that this is similar to previous arrangements, in Figures 1 to 5, but this arrangement depicts an actuator component 103 comprising two cover parts 140a, 140b which extend in the array direction 10, adjacent to the strip of piezoelectric material 120. The cover parts 140a, 140b are fixedly attached to a side face 121a, 121b of the strip of piezoelectric material 120 and to a portion 111a, 111b of the substrate 110. The cover parts 140a, 140b comprise inner faces 145a\_i, 145b\_i, which are fixedly attached to the portions 111a, 111b respectively, and inner faces 145a\_ii, 145b\_ii which are fixedly attached to the side face 121a, 121b respectively. It can further be seen that Figure 6 depicts an actuator component 103 comprising a respective cover part 140a, 140b on each side of the strip of piezoelectric material 120, wherein both said cover parts 140a, 140b comprise a plurality of openings 141a, 141b respectively. It should be understood that the strip of piezoelectric material 120 of Figure 6 is the same as that of Figures 1-5, consequently the height  $H$ , width  $W$  and length  $L$  of the fluid chambers 131 in Figure 6 are not labelled. In this implementation, the openings 141a, 141b are shallower than the fluid chambers 131, such that their heights  $h_a$  and  $h_b$  are less than the height  $H$  of the fluid chambers 131 ( $h_a < H$ ,  $h_b < H$ ), whilst their widths equal that of the fluid chambers 131

( $w_a=w_b=W$ ) and, as before, their lengths are less than that of the fluid chambers 131 ( $l_a<L$ ,  $l_b<L$ ).

In alternative arrangements to that shown in Figure 6, it may be that the width of the openings 141a, 141b is altered relative to the fluid chambers 131 such that ( $w_a<W$ ,  $w_b<W$ ), this may be as well as or instead of altering the heights  $h_a$  and  $h_b$ . It should be understood that in some arrangements, as depicted in Figure 6, it is desirable that the openings 141a, 141b in the cover parts 140a and 140b are the same, such that they have the same heights ( $h_a=h_b$ ) and lengths ( $l_a=l_b$ ) and widths ( $w_a=w_b$ ) and hence the cross-sectional areas of the openings ( $A_{oa}=h_a*w_a$ ,  $A_{ob}=h_b*w_b$ ) may be the same ( $A_{oa}=A_{ob}$ ), such that the openings 141 in the cover parts 140a, 140b on each side of the one or more strips of piezoelectric material 120 have the same length and/or the same width and/or the same height and/or the same cross-sectional area.

In further alternative arrangements, by altering the length,  $l_a$ ,  $l_b$ , in the fluid chamber extension direction 5 of the one or more cover parts 140a, 140b, the actuator component 103 may comprise fluid chambers 131 that are elongate in a fluid chamber extension direction 5, which is at an angle to said array direction 10, wherein the length,  $l$ , of the plurality of openings 141 in the fluid chamber extension direction 5 is less than or equal to the length,  $L$ , of the fluid chambers 131 ( $l\leq L$ ). The length,  $l$ , of the openings 141 in the fluid chamber extension direction 5 can be controlled, for example, by utilising different sizes of cover part 140, or by cutting, machining or otherwise altering the cover parts 140 so as to reduce the length  $l_a$ ,  $l_b$ , so as to produce different actuator component designs 101, 102, 103.

Turning now to Figure 7, this depicts an actuator component 104, which is similar to the actuator component 103 depicted in Figure 6. This means that the fluid chambers in the array 130 of fluid chambers have the same height  $H$ , length  $L$  and width  $W$  as in Figures 5 and 6, and the openings 141a, 141b have the same height  $h_a$ ,  $h_b$ , length  $l_a$ ,  $l_b$  and width  $w_a$ ,  $w_b$  as in Figure 6. The main difference between the embodiments depicted in Figures 6 and 7 is that in Figure 7 the openings 141a, 141b are formed in the cover parts 140a, 140b such that every other fluid chamber 131c is connected to openings 141a and 141b, so that it is open at both ends (so-called 'open' or 'wet' channels), and every other fluid chamber 131d is left

blocked off at either end (so-called ‘dummy’ or ‘dry’ channels). In other words, the number of openings 141a, 141b, in each cover part 140a, 140b is half the number of fluid chambers 131 (or alternatively described, equal to the number of ‘wet’ fluid chambers 131c), and the openings 141a, 141b, in the cover parts 140a, 140b are aligned so as to selectively leave  
5 alternate open fluid chambers 131c such that, when installed in a part of a droplet ejection head 20, as per Figure 4, they are fluidically connected to an inlet manifold channel 201 and an outlet manifold channel 202 so as to allow fluid to flow therethrough.

Thus Figure 7 depicts an actuator component 104 where there is at least one opening 141a,  
10 141b per strip of piezoelectric material for every other fluid chamber 131c. This is a so-called Alternate Line Active (ALA) design which is suitable for use with, for example, aqueous fluids such as aqueous inks/fluids or with conductive fluids, because the actuator component 104 includes open or ‘firing’ fluid chambers 131c, from which fluid may be ejected through nozzles, as well as dummy or ‘non-firing’ chambers 131d, which are  
15 configured such that they are unable to eject droplets. Accordingly, this is an example of an actuator component 104 where there are fewer openings 141 per cover part 140 than there are fluid chambers 131 per strip of piezoelectric material 120. Firing chambers and non-firing chambers are typically alternately arranged, and the non-firing chambers do not allow fluid to travel therethrough and do not comprise a nozzle. It may therefore be understood  
20 that when an actuator component with ALA, such as that in Figure 7, is incorporated in a part of a droplet ejection head 20, such as that depicted in Figure 4, the number and location of the nozzles 221 in the nozzle wafer 220 is adjusted to align with and match the number of open fluid chambers 131c. It may further be understood that the non-firing chambers 131d may contain the drive electrodes, which in this way are physically isolated from contact with  
25 the fluid, such as ink.

This type of ALA design offers several advantages. For example, this configuration can be used in order to allow aqueous inks to be jetted by placing the drive electrodes in the non-firing chambers 131d. In operation the non-firing chambers 131d are sent an electrical  
30 signal, whereas the firing chambers 131c through which the fluid flows are held at ground. Since electrodes with different potentials are not in contact with the fluid the risk of failure caused by the presence of ionic species in the fluid is removed and the electrodes in the non-

firing chambers 131d do not need any passivation. Such a design may also be used to reduce the mechanical crosstalk between fluid chambers 131c, since they do not share actuator walls. However, a disadvantage is the loss of resolution by doubling the distance between adjacent nozzles. The limitation to resolution is the machinability of the piezoelectric material to create thinner walls while keeping the firing chamber 131c dimensions the same to retain acoustic actuation properties. The loss of resolution may be mitigated by using narrower non-firing chambers 131d and hence reducing the distance between adjacent firing chambers 131c and their nozzles 221. For example the non-firing chambers 131d may be half the width of the firing chambers 131c ( $w_d = w_c/2$ ), or any other suitable ratio of  $w_d:w_c$ . An ALA design may not just be beneficial for aqueous fluids; it may also enable faster print speeds (possibly three times faster) to be used with non-aqueous fluids, leading to productivity improvements.

Considering Figure 7 further, in this embodiment, the openings 141a and 141b on either side of the strip of piezoelectric material 120 are the same, and have widths  $w_a$  and  $w_b$  and heights  $h_a$ ,  $h_b$ , that are equal to the width of the fluid chambers 131, such that  $w_a = w_b = W$  and  $h_a = h_b = H$ . As in Figure 6, the openings 141a, 141b have lengths  $l_a$  and  $l_b$ , which in this embodiment are the same as each other and less than the length of the fluid chambers 131 such that  $l_a = l_b < L$ . It should be understood that in other implementations it may be desirable to have a design where there is both ALA and also at least one restrictor per open fluid chamber 131c upstream and/or downstream of the fluid chambers 131c, such that as well as only opening up the fluid chambers 131c, either or both of the openings 141a, 141b may be narrower than the fluid chambers 131c, e.g.  $w_a < W$ ,  $w_b < W$  (similar to the arrangement depicted in Figure 1) and/or shallower than the fluid chambers 131c, e.g.  $h_a < H$ ,  $h_b < H$  (similar to the arrangement of Figure 5). Further, as previously described with reference to Figure 6, there is no requirement that the openings 141a, 141b are the same, though in some embodiments it may be desirable that the openings 141a, 141b are the same, such that the cover parts are symmetric across the strip of piezoelectric material 120 (e.g.  $w_a = w_b$ ,  $h_a = h_b$ ,  $l_a = l_b$ ).

It should be understood that the actuator components 102, 103, 104 could be used instead of the actuator component 101 in the part of the droplet ejection head 20 of Figure 4, as could

any variant of any of the actuator components described herein. Therefore, the actuator component may comprise a single cover part per strip of piezoelectric material, or it may comprise a respective cover part on each side of the strip of piezoelectric material 120, wherein each of said cover parts 140a, 140b comprises a plurality of openings. Further, irrespective of whether there is a single cover part or a cover part on each side, the actuator component may comprise a plurality of fluid chambers 131 and a plurality of openings 141 which both have a width in the array direction 10, and wherein the width of the openings,  $w$ , is less than or equal to the width of the fluid chambers  $W$  ( $w \leq W$ ) or less than the width of the fluid chambers ( $w < W$ ); and/or the fluid chambers 131 and said plurality of openings 141 may have a height in a fluid chamber height direction 15, wherein the height,  $h$ , of the openings is less than or equal to the height,  $H$ , of the fluid chambers ( $h \leq H$ ). Further, the actuator component may comprise fluid chambers 131 and a plurality of openings 141 that have a cross sectional area in the array direction 10, where the cross sectional area of the openings ( $A_o$ , where in this example  $A_o = w * h$ ) is less than or equal to the cross sectional area of the fluid chambers ( $A_c = W * H$ ) such that  $A_o \leq A_c$ . It should be understood that for a restrictor design, where the plurality of openings on one or both sides of the strip of piezoelectric material act to restrict the flow, an actuator component 101, 102, 103, 104 may comprise a plurality of openings 141 whose cross-sectional area  $A_o$  in the array direction 10 is less than the cross-sectional area  $A_c$  of the fluid chambers 131 in the array direction ( $A_o < A_c$ ), either by modifying the height  $h$  and/or the width  $w$  of the openings 141, whilst an ALA design may, or may not, also comprise a restrictor design, depending on operational requirements.

Considering now Figure 8, this depicts an actuator component 105 similar to those of Figures 6-7, with cover parts 140a, 140b on each side of the strip of piezoelectric material 120. The main difference is that the openings 141a, 141b comprise a plurality of sub-openings 147a(i-iii) and similarly 147b(i-iii) (not labelled) with a cross-sectional area  $A_{so}$ . In this particular implementation each opening 141 comprises three circular sub-openings 147(i-iii) diameter  $\phi$ , which may conveniently be formed using laser ablation, for example. It should be understood that in an implementation with sub-openings 147 the cross-sectional area  $A_o$  of an opening 141 is the sum of the areas of all of the sub-openings 147, e.g. in the implementation of Figure 8 where there are three sub-openings 147(i-iii)

$A_o = 3 * A_{so} = 3 * (\pi/4) * \phi^2 \leq A_c$ . The actuator component 105 therefore comprises fluid chambers 131 and a plurality of openings 141 which have a cross sectional area  $A_o$  in said array direction 10, where the cross sectional area  $A_o$  of the openings 141 is less than or equal to the cross sectional area  $A_c$  of the fluid chambers 131 in the array direction 10, and where the cross-sectional area  $A_o$  of the openings 141 is the sum of the areas of the sub-openings 147. It may be understood that the sub-openings 147 are not particularly limited to any shape or form, and that the calculation of the area  $A_{so}$  of the sub-openings may be adjusted according to their shape.

It may also be observed that in the arrangement of Figure 8 the cover parts 140a, 140b are narrower than in previous implementations, such that the length  $l$  of the openings 141 is considerably less than the length  $L$  of the fluid chambers 131 ( $l \ll L$ ). As previously described with reference to Figure 6, the length  $l$  of the cover parts 140 may be controlled by various methods, such as altering the initial dimensions of the cover parts or by altering them in situ by suitable cutting methods or the like. Alternatively the cover parts may be formed from a material such as a flexible film strip, such as Upilex 50S, which may be attached to the strip of piezoelectric material 120 using any suitable method, such as glue or adhesive strips.

Figure 9a depicts an actuator component 106 according to another embodiment at a point when the cover parts 140 have yet to be attached. In this implementation two strips of piezoelectric material 120\_1 and 120\_2 have been fixedly attached to the substrate 110 and a chamfer 122 applied to their upper edges so as to provide a trapezoidal cross-section to each piezoelectric strip in the chamber extension direction 5. Arrays of fluid chambers 130\_1 and 130\_2 have been formed in the strips of piezoelectric material 120\_1, 120\_2 extending in the array direction 10. For clarity the arrays of fluid chambers 130\_1, 130\_2 are depicted as several discrete regions of fluid chambers 131 along the length of the strips of piezoelectric material 120\_1, 120\_2 but it should be understood that in actuality the fluid chambers 131 extend along substantially all of the length of the strips of piezoelectric material 120\_1, 120\_2. In this example the strip of piezoelectric material 120\_1, 120\_2 (and hence the fluid chambers) may have a length  $L$  in the fluid chamber extension direction 5 of between 1500 and 2500 $\mu\text{m}$ , a height  $H$  in the chamber height direction 15 of between 300

and 500  $\mu\text{m}$ , for example 350 to 400 $\mu\text{m}$ , and a width W in the array direction 10 of 50 to 100 $\mu\text{m}$ . In a non-limiting example  $L=1900\mu\text{m}$ ,  $H=380\mu\text{m}$  and  $W=70\mu\text{m}$ .

It may also be seen from Figure 9a that, in this arrangement, the substrate 110 comprises a plurality of inlet ports 211 in a single row, and a plurality of outlet ports 212\_1 and 212\_2 arranged in two rows, where each row of ports 211, 212\_1, 212\_2 extends in the array direction 10. It may further be seen that when the actuator component 106 is fully assembled the plurality of inlet ports 211 will be fluidically connected to a common inlet manifold 201 located between the arrays of fluid chambers 130\_1 and 130\_2, and that each array of fluid chambers 130\_1, 130\_2 will be fluidically connected to separate outlet manifolds 202\_1 and 202\_2, which are then each fluidically connected to a respective row of outlet ports 212\_1, 212\_2.

Turning now to Figures 9b and 9c, these depict a detail at one end of the actuator component 106 of Figure 9a. It can be seen that the actuator component 106 comprises a substrate 110 and two strips of piezoelectric material 120\_1, 120\_2 fixedly attached to said substrate 110; wherein the strips of piezoelectric material 120\_1, 120\_2 comprise one or more layers of piezoelectric material. The strips of piezoelectric material 120\_1, 120\_2 comprise an array of fluid chambers 130\_1, 130\_2 defined within said one or more strips of piezoelectric material 120\_1, 120\_2 and extending in an array direction 10. The actuator component 106 further comprises cover parts 140\_1a, 140\_1b, 140\_2a, 140\_2b (See Figure 9c); wherein each of said cover parts 140\_1a, 140\_1b, 140\_2a, 140\_2b extends in the array direction 10 and is fixedly attached to at least one of a side face of one of said strips of piezoelectric material 120\_1, 120\_2 and/or at least a portion of said substrate 110. Further, the cover parts 140\_1a, 140\_1b, 140\_2a, 140\_2b comprise a plurality of openings 141\_1a, 141\_1b, 141\_2a, 141\_2b so as to enable fluid to be supplied to selected ones of said fluid chambers 131 through said openings 141\_1a, 141\_1b, 141\_2a, 141\_2b.

It can be seen that in the arrangement of Figures 9b and 9c there are a plurality of cover parts 140\_1a, 140\_1b, 140\_2a, 140\_2b that have been attached so that there is a respective cover part 140 fixedly attached on each side of each of the strips of piezoelectric material 120\_1 and 120\_2 and extending in the array direction 10. The cover parts 140 comprise a plurality

of openings 141\_1a, 141\_1b, 141\_2a, 141\_2b. It can be seen from the detail views of Figures 9b and 9c that there are fewer openings 141 than fluid chambers 131 such that each cover part 140\_1a, 140\_1b, 140\_2a, 140\_2b comprises at least one opening 141\_1a, 141\_1b, 141\_2a, 141\_2b for every other fluid chamber 131c over a substantial portion of the array.

5 That is to say, this is an example of an ALA design, similar to that depicted in Figure 7. Further, it can be seen that in this embodiment, as in Figure 7, the openings 141 offer no restriction to the fluid flow, e.g. they are a continuation of the form and shape of the fluid chambers 131, with the same cross-sectional area,  $A_o=A_c$ .

10 It should be understood that where, as in Figures 9a-9c, the strips of piezoelectric material 120\_1, 120\_2 have a trapezoidal shape, and hence the fluid chambers 131 have a non-cuboidal shape, the cross-sectional area  $A_c$  of the fluid chambers 131 may be the cross-sectional area calculated perpendicular to the chamber extension direction 5 in the chamber height direction 15 outside the tapered regions at the ends of the trapezoid. Likewise the

15 cross-sectional area  $A_o$  of the openings 141 is the projected cross-sectional area calculated perpendicular to the chamber extension direction 5 in the chamber height direction 15. In such a design, where the openings 141\_1a, 141\_1b, 141\_2a, 141\_2b are acting to selectively open up alternate fluid chambers 131\_1c, 131\_2c, the cover parts 140\_1a, 140\_1b, 140\_1c, 140\_1c have been formed as narrow strips extending in the array direction 10 on either side

20 of the strips of piezoelectric material 120\_1, 120\_2, such that the length  $l$  of the openings is much less than the length  $L$  of the fluid chambers ( $l \ll L$ ).

Considering Figure 9c, which is a detail of Figures 9a and 9b, it can be seen that the fluid chambers 130\_1, 130\_2 and the openings 141\_1a, 141\_1b, 141\_2a, 141\_2b comprise a main

25 region 160 and a buffer region 150, where the buffer region 150 is adjacent to the longitudinal ends of the strips of piezoelectric material 120\_1, 120\_2 in the array direction 10. The main region 160 starts after the buffer region 150 finishes and extends in the array direction 10. A similar, second buffer region 150 may exist at the opposite end of the strips of piezoelectric material 120\_1, 120\_2 in the array direction 10, with the main region 160

30 finishing before the second buffer region 150 commences (see, for example, Figure 9a). In the arrangement depicted in Figures 9a-9c the fluid chambers 131 in the main region 160 and the buffer region 150 have the same cross-sectional area. In this arrangement the fluid

chambers 131 in the buffer region 150 have no nozzles (not shown), so cannot eject ink, but, in use, allow fluid to travel therethrough. It is believed that this arrangement improves the flow uniformity along the actuator component 106 in the array direction 10 and also aids in improving the stress profile along the actuator component 106 in the array direction 10 and therefore improves the droplet ejection performance and print quality (as stress in actuator components such as those described herein can lead to flow non-uniformity that ‘prints through’ into observable defects in the printed image or product).

It should be understood that, in other arrangements, the buffer region(s) 150 may comprise fluid chambers 131 and/or openings 141 that are configured differently to those in the main region 160. For example, the fluid chambers 131 (and hence openings 141) in the buffer region(s) 150 may be spaced differently (closer together or further apart). Alternatively, the fluid chambers 131 in the buffer region(s) 150 may be wider/narrower or taller/shallower; or they may not have a metallic layer or layers in them, such that  $Ac_{150} \neq Ac_{160}$ . Further, the fluid chambers 131 in the buffer region 150 may not be actuated/ may be driven differently in any driving schemes when the actuator component 106 is installed in a droplet ejection head 20, so that the fluid chambers 131 do not act to eject droplets. Still further, in some arrangements, the fluid chambers 131 in the buffer region 150 may not comprise nozzles 221 (not shown in Figure 9c).

In alternative arrangements the fluid chambers 131 in the buffer region 150 may be the same as the fluid chambers in the main region 160 such that  $Ac_{150} = Ac_{160}$ , but the openings 141 in the buffer region 150 may be different to those in the main region 160. For example, in a design where the main region is ALA (openings 141 for every other fluid chamber 131), the fluid chambers 131 in the buffer region 150 may have an opening 141 for every fluid chamber 131; alternatively there may be unopened (dummy) fluid chambers 131 in the buffer region 150, whether or not the main region 160 is an ALA design, such that the actuator component comprises fewer openings 141 per cover part 140 than fluid chambers 131 per strip of piezoelectric material.

In some arrangements the openings 141 in the buffer region 150 may be wider/narrower or taller/shallower than in the main region 160, such that  $Ao_{150} \neq Ao_{160}$ . Alternatively, in a

design comprising openings 141 that act as restrictors (with or without ALA), where the openings 141 in the main region 160 have a cross-sectional area  $Ao_{160} < Ac_{160}$ , the buffer region(s) 150 at either or both ends of the array 130 of fluid chambers may comprise openings 141 that are equal to the width  $W_{150}$  ( $w_{150} = W_{150}$ ) or height  $H_{150}$  ( $h_{150} = H_{150}$ ), or cross-sectional area  $Ac$  ( $Ao_{150} = Ac_{150}$ ), of the fluid chambers 131 in the buffer region 150; or may be equal to the width or height, or cross-sectional area, of the fluid chambers 131 excluding the thickness of any coating layers the fluid chambers may comprise (e.g. the metallic and coating layers may not be formed, or may be removed from the fluid chambers 131 in the buffer region 150). Alternatively the openings 141 may have a different width and/or height and/or cross-sectional area to the fluid chambers 131 in the buffer region 150. Further the openings 141 may have a different width and/or height and/or cross-sectional area to the openings 141 in the main region 160. It should be understood that in some implementations such a buffer region 150 may be of benefit to the fluidic flow performance within the droplet ejection head 20, or to improve the stress profile within the actuator component, both of which may affect the droplet ejection performance.

Still further the buffer region(s) 150 may comprise two or more sub-buffer-regions with different arrangements of fluid chambers 131 and/or openings 141 in the two or more sub-buffer-regions, so as to address different requirements of the printhead such as fluidic performance or stress relief in the actuator component.

Considering Figure 9a further, it can be seen that when the actuator component 106 is installed in a droplet ejection head 20 the arrangement may be such that there is a single inlet manifold channel 201 and double outlet manifold channels 202\_1 and 202\_2, though this is by no means necessary and in other arrangements there may be other configurations of inlet and outlet manifold channels, though at least one of said manifold channels is fluidically connected to one or more inlets. Further, where there are two or more manifold channels, at least one may be fluidically connected to one or more outlets.

In some arrangements it may be desirable to modify the width  $w$  of the openings 141 such that the actuator component comprises openings 141 whose width  $w$  is different in different parts of the array 130 of fluid chambers, for example where the buffer region 150 comprises

openings 141 whose width  $w_{150}$  is different to the openings 141 in the main region 160. Alternatively, or as well, the width  $w$  of the openings 141 on one or both sides of the one or more strips of piezoelectric material 120 may increase with increasing distance from each of said one or more inlet ports 211 and/or each of said one or more outlet ports 212. For example, considering again Figure 9a, it can be seen that the substrate 110 comprises a plurality of inlet ports 211 and a plurality of outlet ports 212\_1 and 212\_2. An arrangement where the width  $w$  of the openings 141 on one or both sides of the strip of piezoelectric material 120 increases with increasing distance from an inlet 211 and/or outlet port 212\_1 and 212\_2 may improve the fluid flow performance. For example it may improve the consistency of the fluid supply to all of the fluid chambers 131, so that those closer to the ports 211, 212\_1 and 212\_2 are not preferentially supplied with fluid.

Figures 9b and 9c depict an actuator component 106 where the cover parts 140\_1a, 140\_1b, 140\_2a, 140\_2b have been shaped such that the cover parts comprise one or more outer faces that are not fixedly attached to a part of one of said strips of piezoelectric material 120\_1, 120\_2 or to at least a portion of the substrate 110, and wherein at least one of said outer faces comprises a shaped profile. In the arrangement of Figures 9b and 9c they comprise a chamfer 144 wherein the chamfer 144 is substantially parallel to a chamfer 122 on the underlying strip of piezoelectric material 120\_1, 120\_2, though it should be understood that this is by no means essential and in other arrangements the chamfer 144 may be at a different angle to the chamfer 122.

Figure 9d depicts an alternative actuator component 107, similar to that of Figures 9b and 9c, the main difference being that the outer faces of the cover parts 140\_1a, 140\_1b, 140\_2a, 140\_2b have a stepped profile 143\_1a, 143\_1b, 143\_2a, 143\_2b. Such steps may act to deflect pressure waves away from the openings 141 and thereby reduce cross-talk between fluid chambers. It should be understood that in other arrangements the cover parts 140\_1a, 140\_1b, 140\_2a, 140\_2b may have any suitable and achievable shaped profile 143 on one or more of the outer faces of the one or more cover parts 140\_1a, 140\_1b, 140\_2a, 140\_2b, such that said shaped profile comprises a chamfer 144, or a concave or convex profile or a stepped profile extending along the length of the cover part in the array direction 10.

Figure 10a depicts an actuator component 107 where the cover parts 140\_1a, 140\_2a, 140\_1b, 140\_2b have been built up by depositing a layer or a series of layers of a flowable flexible material – for example a resin (e.g. Delo OB787 adhesive) may be applied to the strip(s) of piezoelectric material 120\_1, 120\_2 and to the substrate 110. It should be understood that other materials may be used, such as a UV curable resin, or a polymer resin, or other adhesives or glues, or any suitable polymer, for example any material that is flowable and/or suitably deformable. As an example, consider Figure 10b, which shows schematically a single dry fluid chamber 131d with layers of cover parts 140\_2ai-iii, 140\_2bi-iii attached to the outside of the strip of piezoelectric material 120 and to the substrate 110. Such cover part material layers 140\_2ai-iii, 140\_2bi-iii may then harden or be hardened in situ. For example, some materials may harden with time, or be UV curable or thermally curable. The layers may deform and fuse together into a homogenous whole, or remain as distinct but attached layers.

Considering the arrangement of Figure 10a further, it should be understood that such cover parts 140\_1a, 140\_2a, 140\_1b, 140\_2b may also comprise layers with differing properties, so as to form a multilamellar solid block with different layers providing complementary properties such as adhesion, compliance, chemical resistance etc. It could also comprise a multiphase block incorporating air gaps to allow pulse damping, low dielectric insulation and compliance. The compliance of the cover parts 140\_1a, 140\_2a, 140\_1b, 140\_2b may be adjusted to optimise performance by changes in chemistry and/or the inclusion of gas bubbles. The advantage of using such a flexible material is that the design can be readily altered and implemented and the internal geometry and fluid flow path of the actuator component 107 can be changed readily with high resolution.

Considering now Figures 10c and 10d, in some ALA arrangements the cover parts 140 may instead comprise filling some or all of the dry fluid chambers 131d. For example, the cover parts may comprise pillars 148\_a, 148\_b at the ends of the fluid chambers 131d (as in Figure 10c) with an air gap 249 in the remainder of the fluid chamber 131d, or they may be filled entirely with a fill 149 (as in Figure 10d). Still further the air gap 249 may be replaced with a fill 249 with chosen properties, such as electrical passivation or high levels of compressibility so as to deform readily when the fluid chamber walls are deflected in

operation. It may further be understood that in some arrangements the implementations of Figures 10a and 10b, with external cover parts 140\_1a, 140\_2a, 140\_1b, 140\_2b, may be combined with the arrangements of Figures 10c or 10d so as to comprise cover parts that are both external and attached to the strip of piezoelectric material 120, and that also comprise parts that partially or completely fill the dry fluid chambers 131d such as pillars 148 or a complete fill 149 or pillars 148 and a fill 249 of one or more materials. Still further, internal fills or pillars and fills may be combined with any of the actuator components described herein.

Turning now to Figure 11a, this summarises the main steps in a method of manufacturing an actuator component for a droplet ejection head 20 as described herein. Figure 11b depicts an alternative method of manufacture for an actuator component as described herein, where some of the steps have been re-ordered. Figures 12a to 12g depict the main steps; as follows:

Step 300: fixedly attaching one or more strips of piezoelectric material 120 to a substrate 110, as depicted in Figures 12a and 12b (in this instance two strips 120\_1 and 120\_2). This step may comprise fixedly attaching a larger piece of piezoelectric material to the substrate 110 and then cutting or forming or machining the larger piece so as to form one or more strips of piezoelectric material 120. It may be seen that in the example in Figures 12a and 12b a row of inlet ports 211 and two rows of outlet ports 212 have been formed in the substrate 110. It may be understood that the ports may be formed before the strips of piezoelectric material 120 have been attached to the substrate 110, after the strips of piezoelectric material 120 have been attached, or they may suitably be formed at a later stage in the manufacturing process.

Step 300a: optionally, forming chamfers 122 on the upper edges of said one or more strips of piezoelectric material 120, as shown in Figure 12b, so as to form a trapezoidal cross-section. This step is optional, depending on the required cross-sectional shape of the strips of piezoelectric material.

Step 310: forming one or more arrays of fluid chambers 130\_1 and 130\_2 in the one or more strips of piezoelectric material 120, as shown in Figure 12b, so as to create a plurality of

open-ended channels or fluid chambers 131 in said one or more strips of piezoelectric material 120, wherein the fluid chambers 131 are aligned in an array direction 10 along the one or more strips of piezoelectric material 120. Each fluid chamber 131 is formed such that it comprises an open channel in the strip of piezoelectric material 120 with an opening at  
 5 either end in the fluid chamber extension direction 5 and such that the fluid chambers 131 are also open along their extent on the opposite side to the substrate 110 in the fluid chamber height direction 15.

Any suitable method may be used to form the fluid chambers 131, such as laser cutting, or  
 10 cutting with a dicing blade or saw, or using a water jet cutter, or any other suitable cutting tool. As an example, dicing blades may be between  $3\mu\text{m}$  and  $160\mu\text{m}$  wide. Depending on the required design, the fluid chambers 131 may be formed with any suitable width,  $W$ , depending on the dicing blade chosen; for example they may be between  $50\mu\text{m}$  and  $100\mu\text{m}$  wide. The height,  $H$ , of the fluid chambers 131 may be controlled by altering the path and  
 15 position of the dicing blade, for example so as to form the fluid chambers 131 to any suitable height  $H$ , where a suitable height  $H$  may be between  $25\mu\text{m}$  and  $600\mu\text{m}$ , preferably between  $100\mu\text{m}$  and  $500\mu\text{m}$ , more preferably between  $300\mu\text{m}$  and  $450\mu\text{m}$ , still more preferably between  $350\mu\text{m}$  and  $410\mu\text{m}$ . For example, a fluid chamber 131 may have a height  $H$  of  $360\mu\text{m}$ ,  $370\mu\text{m}$ , or  $380\mu\text{m}$  to a tolerance of  $\pm 15\mu\text{m}$ . To form the fluid chambers 131 the  
 20 dicing blade may be lowered towards the substrate 110 to one side of the strips of piezoelectric material and then moved across the strips of piezoelectric material 120 in the fluid chamber extension direction 5 so as to form all of the fluid chamber(s) 131 at a given position in the array direction 10. The dicing blade may then be lifted and returned to its original position, and the actuator component may be incrementally moved in the array  
 25 direction 10 so that the next row of fluid chamber(s) 131 may be formed.

Step 320: forming electrical tracks and connections (not shown) in a plurality of said fluid chambers 131. This step may be performed using any suitable method. For example, metallic layer(s) may be deposited over the substrate 110, piezoelectric strips 120 and into the array  
 30 130 of fluid chambers and then some of the metal layer may be removed to form metal tracks and electrodes (for example using a laser to ablate some of the metal layer). Alternatively, other methods could be used such as using a photoresist or masking to form the tracks and

electrodes. Step 320 may, optionally, also comprise depositing one or more coating layers for passivation and/ or insulation of said electrical tracks and connections. Alternatively, the coating layer(s) may be formed at a later stage, e.g. at any point after electrodes have been formed.

5

Step 330: forming a wafer 142 that is conformal to at least some of said one or more strips of piezoelectric material 120 and at least some of said substrate 110, as shown in Figure 12c, wherein said wafer 142 comprises one or more parts. For example, the wafer 142 may comprise a single layer of material, or be formed from a number of layers of material fixedly  
 10 attached together. Alternatively it may comprise a number of component parts, for example a number of parts that have been pre-shaped to be conformal to a particular part of the strips of piezoelectric material 120 or the substrate 110 that are then fixedly attached together.

The wafer 142 may be shaped by machining or moulding or any suitable manufacturing  
 15 technique, or the component parts may be formed and then assembled and then further shaped using any suitable manufacturing technique, such as cutting or grinding or laser ablating. The material of the cover wafer 142 may be the same material as the strips of piezoelectric material, or a different material. The material of the cover wafer 142 may comprise a material that is acoustically the same or similar to the strips of piezoelectric  
 20 material 120 and/or the substrate 110.

In an alternative method the wafer 142 may comprise a conformable material and the method of manufacture may involve vacuum forming a conformable film to a required shape, either in situ over the actuator component 101-107 or over an external form whereby the film is  
 25 then cured and, if necessary, further machined or cut to shape and, if formed on an external form, then attached to the actuator component 101-107.

Step 340: fixedly attaching at least a part of said wafer 142 to said substrate 110 and at least a part of said wafer 142 to said one or more strips of piezoelectric material 120, as shown in  
 30 Figure 12d, and in cross-section in Figure 12e. The attachment method may comprise gluing using any suitable adhesive. The gluing method may comprise depositing or 3D printing a glue in appropriate locations. The glue may be curable, e.g. thermal curable glue, or if the

cover wafer is formed from a UV transparent material a UV curable glue may be used. Epoxy glues – glues that are curable in a temperature range that doesn't damage or otherwise compromise the PZT performance – may be used; they may for example be curable below 140°C, more preferably below 120°C.

5

As an alternative to a flowable glue, films of adhesive material may be applied as a layer between the wafer 142 and the strip of piezoelectric material 120 and the substrate 110, and then the film may be cured or otherwise treated to ensure adhesion.

10 Step 350: removing material from said wafer 142 and thereby forming one or more cover parts 140 which are fixedly attached to a face of one of said strips of piezoelectric material 120 and at least a portion of said substrate 110, as shown in Figure 12f. The material may be removed by any suitable method or combination of methods, such as cutting and/or grinding the wafer 142, for example whereby removing material from the wafer 142  
15 comprises grinding or cutting said wafer from the side opposite to that fixedly attached to the substrate 110 so as to form the one or more cover parts 140. In embodiments such as that depicted in Figure 9a the method of manufacture of the actuator component may comprise forming a respective cover part 140 on each side of said one or more strips of piezoelectric material 120.

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Step 350a: optionally, shaping the cover parts, for example forming chamfers 122 on the upper edges of some of said one or more cover parts 140, as shown in Figure 12g (or other shapes, as described with reference to Figure 9d – e.g. wherein said shaped profile comprises a chamfer 144, or a concave or convex profile or a stepped profile extending along the length  
25 of the cover part in the array direction 10). The chamfers 122 may be formed parallel to the chamfers on the strips of piezoelectric material 120, or inclined at a different angle. They may also be formed where the strips of piezoelectric material 120 have not been chamfered. Chamfers may be desirable in some implementations as it may make it easier to perform the laser track cutting at a later stage in the process. In other implementations the cover parts  
30 140 may be trimmed and/or chamfered so as to form different lengths of openings 141 by altering the position of the chamfer-forming or trimming tool(s) relative to the cover parts 140. For example, where the fluid chambers 131 are elongate in a fluid chamber extension

direction 5 which is at an angle to the array direction 10, the length,  $l$ , of the openings 141 in the fluid chamber extension direction 5 can be controlled by removing more or less material from the cover parts 141 (or alternatively by using different designs of wafer 142 from which to form the cover parts 141).

5

Considering Figure 12g further, it can be seen that the cover parts 140 do not extend all the way across the substrate because a channel 143 was formed in the wafer 142 (see Figure 12c); this means that the ports 211 are not covered by the cover part(s) 140. This is by no means essential and in other arrangements the cover parts 140 may be shaped differently so as to comprise a part that additionally covers the region of substrate 110 between the strips of piezoelectric material 120. In this case the ports 211/212 may be formed after the cover parts 140 have been formed, so as to pass through both the substrate 110 and the cover part 140, rather than forming the ports 211/212 when preparing the substrate 110. Alternatively the ports 211/212 may be formed in the substrate 110 as before, and then further holes formed through the relevant section of the cover part 140 to open up the ports 211/212.

15

Step 360: forming a plurality of openings 141 in said cover parts 140 to form an actuator component as depicted in Figures 9b-9d. The openings 141\_1a, 141\_1b, 141\_2a, 141\_2b may be formed by any suitable method, such as laser cutting, or cutting with a dicing blade or cutter. Depending on the method used, the width and/or height of the openings 141\_1a, 141\_1b, 141\_2a, to 141\_2b may be controlled. For example, by using different widths of dicing blades, different widths  $w$  of the openings 141\_1a, 141\_1b, 141\_2a, to 141\_2b can be cut – for example forming openings 141\_1a, 141\_1b, 141\_2a, to 141\_2b whose width,  $w$ , in the array direction 10 is less than or equal to the width,  $W$ , of the fluid chambers 131.

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Further the depth to which the cut is made can be controlled so as to control the height,  $h$ , of the openings 141\_1a, 141\_1b, 141\_2a, to 141\_2b, wherein the height,  $h$ , of the openings 141\_1a, 141\_1b, 141\_2a, 141\_2b can be controlled to be less than or equal to the height,  $H$ , of the fluid chambers 131.

25

Still further the cross-sectional area  $A_o$  of the openings 141\_1a, 141\_1b, 141\_2a, 141\_2b may be controlled to be less than or equal to the cross-sectional area of the fluid chambers

30

Ac. Still further the length  $l$  of the openings 141\_1a, 141\_1b, 141\_2a, 141\_2b in the fluid chamber extension direction 5 may be controlled to be less than or equal to the length  $L$  of the fluid chambers 131. Account may be taken of the location and thicknesses of any coatings  $c1...cn$  on the surface(s) of the fluid chambers 131 so as not to damage said coatings.

The control of the manufacturing parameters can be done so as to alter the size of the openings 141\_1a, 141\_1b, 141\_2a, to 141\_2b at different locations in the array direction 10, for a given design of actuator component 101-107. Alternatively control of manufacturing parameters may be so as to produce different actuator components from the one production line, for example. As an example, cutting blades may be between 30 and 400 $\mu$ m wide; for example they may be available at any desired width within this range. Thicker blades may also be available, at any desired width, up to, for example, 2.2mm wide.

As a non-limiting example the fluid chambers 131 may be, for example 75 $\mu$ m wide, and 65 $\mu$ m wide after deposition of the metal plating layer  $c1$ , and 55 $\mu$ m wide after deposition of the protective coating or passivation layer  $c2$ . A suitable dicing blade or blades may be chosen to cut the openings 141\_1a to 141\_2b to the desired width  $w$ , where  $w < 55 \mu$ m. In another non-limiting example, a 65 $\mu$ m dicing blade may be chosen to form the openings if the cross-sectional area  $A_c$  of the fluid chambers 131 is 65 $\mu$ m after deposition of the metal plating layer  $c1$ . The openings 141\_1a to 141\_2b may be cut and then the coating layer(s)  $c2...cn$  (for example) may be deposited at a later stage, after the openings 141\_1a to 141\_2b have been formed, so that both fluid chambers 131 and openings 141\_1a to 141\_2b are narrowed by the thickness of any protective coating layer(s)  $c2...cn$  that are applied.

Alternatively, other blade thicknesses may be chosen as suitable for the design so as to form restrictor designs where  $A_o < A_c$ , so as to form an actuator component 101 wherein the width,  $w$ , of the openings is less than the width,  $W$ , of the fluid chambers 131 ( $w < W$ ). The plurality of openings 141\_1a to 141\_2b may, for example, be formed by lowering a dicing blade towards the cover parts 140\_1a to 140\_2 and cutting a path through the cover part(s) 140\_1a to 140\_2b, so as to form a plurality of open-ended channels, the openings 141\_1a to 141\_2b.

As part of the cutting process, the dicing blade may also pass through the fluid chambers 131, but without affecting them.

It should be understood that openings 141\_1a to 141\_2b may also be formed using, for example, techniques such as laser ablation, which may be used for forming narrower openings. It may also be understood that the width  $w$  of the openings 141 may be proportionate to the width  $W$  of the fluid chambers 131, therefore where the fluid chambers are wider than  $75\mu\text{m}$ , the openings 141 may be made wider accordingly. As for the formation of the fluid chambers 131, the height,  $h$ , of the openings 141\_1a to 141\_2b may be selectively altered by, for example, altering the vertical position of the dicing blade relative to the substrate 110.

It should be understood that, depending on the design of actuator component 101, 102, 103, 104, 105, 106 (or variants thereof) being manufactured, the number and location of the openings can be controlled. For example, where there is a buffer region 150 and/or where every other fluid chamber 131 is open in at least the main region, so as to form an ALA design, the method of forming a plurality of openings may comprise forming fewer openings 141 than there are fluid chambers 131. Further, where the actuator component enables ALA, the method of manufacturing the actuator component may comprise forming at least one opening for every other fluid chamber 131 over a substantial portion of the array 130 of fluid chambers. Alternatively, where the actuator component does not enable ALA, the method of manufacturing the actuator component may comprise forming at least one opening 141 per fluid chamber over a substantial portion of the array 130 of fluid chambers, for example, where the substantial portion may comprise at least the main region 160.

Further, when manufacturing an actuator component, depending on the type of actuator component that is required, the plurality of openings 141 may be formed in the cover part 140 by a method that involves choosing the number of openings 141 and the width,  $w$ , and/or length,  $l$ , and/or height,  $h$ , of the openings 141 and forming the cover parts 140 from the wafer 142 so as to meet the chosen requirements. For example, the method of manufacturing the actuator component may involve choosing:

an ALA design by forming at least one opening 141 for every other fluid chamber 131 over substantially all of the array 130 of fluid chambers, and/or

5 a restrictor design by forming openings 141 wherein over substantially all of the array 130 of fluid chambers the width,  $w$ , of the openings 141 is less than the width,  $W$ , of the fluid chambers 131 and/or the height,  $h$ , of the openings 141 is less than the height,  $H$ , of the fluid chambers 131 and/or the cross-sectional area of the openings is less than the cross-sectional area of the fluid chambers.

Further, where the actuator component comprises cover parts 141a, 141b on both sides of  
10 the strip(s) of piezoelectric material, the method of manufacturing the actuator component may comprise forming openings 141 of different widths,  $w_a$ ,  $w_b$ , and/or of different heights,  $h_a$ ,  $h_b$ , and/or of different cross-sectional areas on each side of each fluid chamber 131 over a substantial portion of the array of fluid chambers. For example, the openings 141 adjacent  
15 to an inlet manifold channel 201 on one side of the array 130 of fluid chambers may be different to those adjacent to an outlet manifold channel 202 on the other side of the array 130 of fluid chambers in the fluid chamber extension direction 5.

Still further, where the openings comprise sub-openings, the method may comprise forming  
a number of sub-openings for each opening. In addition, where the design is an ALA design,  
20 and/or comprises one or more buffer regions 150 the method may comprise forming pillars and/or a fill in certain fluid chambers 131.

It may be understood that once the above-described manufacturing steps have been performed, further manufacturing steps may also be performed, such that the method may  
25 further comprise fixedly attaching a nozzle wafer 220 to the actuator component 101, 102, 103, 104, 105, 106, 107 so as to fluidically seal said manifold channels 201, 202 and said openings 141 and said array of fluid chambers 131. The nozzle wafer 220 may then have nozzles 221 formed therein, for example by using laser ablation to open up nozzles 221 connecting to the fluid chambers 131, but it should be understood that any suitable method  
30 of forming the nozzles 221 may be utilised; and that they may be formed before or after attaching the nozzle wafer 220 to the actuator component 101, 102, 103, 104, 105, 106, 107, 108. Further manufacturing steps may comprise deposition of protective coating layer(s),

for example using vapour deposition methods such as chemical vapour deposition (CVD) or physical vapour deposition (PVD) or a liquid coating such as an electrophoretic coating, so as to coat the internal surfaces of the actuator component 101, 102, 103, 104, 105, 106, 107, 108 with a protective coating layer c or layers ci-n.

5

Further steps may comprise manufacturing and/or assembling a droplet ejection head 20 comprising one or more actuator components 101, 102, 103, 104, 105, 106, 107, 108 as described herein, where the actuator components 101, 102, 103, 104, 105, 106, 107, 108 may be manufactured according to any of the appropriate manufacturing steps described  
10 herein. It should be understood that manufacturing a droplet ejection head 20 may comprise fluidically connecting an actuator component or components 101, 102, 103, 104, 105, 106, 107, 108 to further parts, such as a fluidic supply system so that the inlet port(s) 211 and (where present) the outlet ports 212 are fluidically connected to inlet(s) and outlet(s) respectively on the outer surface of the droplet ejection head 20, and may also comprise  
15 assembling together further parts, such as electronics components, cover parts etc., so as to form a droplet ejection head 20.

In an alternative arrangement the fluid chambers 131 may be formed with different widths so as to optimise use of space. For example, an ALA design as described herein may  
20 comprise two widths of fluid chamber, W1 and W2, in the main region 160. In such an arrangement, for example, the open fluid chambers 131c may have a width W1 and the dummy (dry) fluid chambers 131d may have a width W2, where  $W2 < W1$ ; for example W2 may be half of W1 ( $W2 = W1 / 2$ ). Cutting narrower dummy fluid chambers 131d would alter the pitch between the firing and non-firing fluid chambers and would allow greater print  
25 resolution for a given size of droplet ejection head.

It should be understood that the process step for manufacturing the fluid chambers, where there are different widths of fluid chambers 131c, 131d, may be adjusted appropriately, for example by changing step 310 into a two-step process and forming one or more arrays 130  
30 of fluid chambers so as to create a plurality of open-ended channels or fluid chambers 131c of width W1 and a plurality of open-ended fluid chambers 131d of width W2 in said one or more strips of piezoelectric material 120, wherein the fluid chambers 131c, 131d are aligned

in an array direction 10 along the one or more strips of piezoelectric material 120. Such a step might, for example, involve using dicing blades of different widths so as to form alternate fluid chambers 131c, 131d of widths W1 and W2 respectively along the strip(s) of piezoelectric material. For example a first blade of width W1 may be used to cut all the fluid chambers 131c of width W1, and then a second blade of width W2 may be used to cut all the fluid chambers 131d of width W2.

Alternatively, such a fluid chamber formation step might involve aligning two dicing blades of different widths W1 and W2 and cutting two fluid chambers 131c, 131d in a single cutting pass, then adjusting the positions of the blades in the array direction 10 and cutting the next pair of fluid chambers 131c, 131d. The end result of either method will be that the array of fluid chambers has fluid chambers 131c, 131d of alternate widths W1, W2 in the array direction 10. The openings 141 are then formed at their desired locations, so as to align with the fluid chambers 131c, using a dicing blade of suitable width, w, where  $w < W1$ .

Turning now to Figure 11b, this depicts a series of process steps that are very similar to those of Figure 11a, except that step 320 has been moved to after step 360, illustrating that the deposition of the metal layers and the formation of the tracks and connections is being done at a later step in the process, after attaching the cover parts 140 and forming the openings 141.

Figures 13a and 13b describe a manufacturing process for an actuator component where the cover parts are formed from an epoxy film or a flowable material such as glue, or any other suitable material, as depicted with reference to Figures 10a to 10d. The steps described in Figure 13a are similar to those described above with reference to Figure 11a, except that steps 330, 340 and 350 have been replaced with steps 330a, 340a and 350a, so that once step 320 (form electrical tracks and connections) has been completed the process moves to:

Step 330a: Form shape over substrate and wall ends. This may involve depositing a layer or layer(s) of flowable material, such as glue, up the sides of the strip of piezoelectric material so as to form the cover part 140, for example as shown in Figure 10b where there are three layers, i-iii. A suitable method may involve using a droplet ejection head or a 3D printer, to

dispense a flowable material such as glue and said material is then cured in situ, e.g. by UV curing, or curing with time, or with thermal energy or by mixing two materials that react together to harden.

- 5 As a non-limiting example a suitable method may involve using a device such as a Nordson Asymtek to dispense glue, such as Delo OB787 adhesive, at 30°C and then heat it to 50°C to allow the layers to flow and spread out evenly and provide a protective layer over a larger region of the electrical tracks and connections. This step may optionally be followed by, for example, a UV cure to fix the glue.

10

Optionally step 340a may be implemented where fills are formed in some or all of any fluid chambers 131 that are to be dummy or dry fluid chambers 131d. Such fills may comprise pillars 148\_a, 148\_b at the ends of the fluid chambers 131d (as in Figure 10c) with an air gap 249 in the remainder of the fluid chamber 131d, or they may be filled entirely with a fill 149 (as in Figure 10d). Still further the air gap 249 may be replaced with a fill 249 with  
15 chosen properties, where said fill 249 may have different electrical or mechanical properties to the pillars 148\_a, 148\_b. It should be understood that the pillars and/or the fills may be deposited as a single layer or built up as a series of layers. Additionally, where several layers are used, the layers may be cured before the next layer is deposited, for example using UV  
20 or thermal curing methods. Additionally, or alternatively, the layers may be cured after all of them have been laid down. A combination of more than one type of cure may be used in some instances.

Step 350, to remove material from the shape to form the cover parts, is similar to that of step  
25 350 described above. For example, it may involve grinding or cutting the shape back to form cover parts 140 that are level with the top of the strip of piezoelectric material 120. Optionally step 350a to shape the cover parts may involve cutting one or more of the outer faces of the cover parts so as to provide a shaped surface, such as steps, or concave or convex surfaces as described previously with reference to Figure 9d.

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Step 360: forming a plurality of openings 141 in said cover parts 140 to form an actuator component as described herein. This process may comprise e.g, sawing or cutting to form the openings. Alternatively techniques such as laser ablation may be used.

5 So put together the steps can be summarised as a method of manufacturing an actuator component for a droplet ejection head, wherein the method comprises the following steps:

Step 300: fixedly attaching one or more strips of piezoelectric material to a substrate;

Step 300a: optionally, chamfering the upper edges of said one or more strips of piezoelectric material, e.g. so as to form a trapezoidal cross-section;

10 Step 310: forming one or more arrays of fluid chambers in said one or more strips of piezoelectric material;

Step 320: optionally, forming electrical tracks and connections;

Step 330a: forming a shape over said substrate and at least a part of said one or more strips of piezoelectric material;

15 Step 340a: optionally forming fills in parts/ all of selected ones of said fluid chambers;

Step 350: removing material from said shape and thereby forming one or more cover parts which are fixedly attached to a face of one of said strips of piezoelectric material and/or to at least a portion of said substrate;

20 Step 350a: optionally shaping an outer surface or surfaces of the cover parts; and

Step 360: selectively forming a plurality of openings in said cover parts so as to enable fluid to be supplied to selected ones of said fluid chambers through said openings.

25 Turning now to Figure 13b, this depicts a series of process steps that are very similar to those of Figure 13a, except that step 320 has been moved to after step 360, illustrating that the deposition of the metal layers and the formation of the tracks and connections is being done at a later step in the process, after attaching the cover parts 140 and forming the openings 141.

30 It may be understood that any of the implementations described herein may be combined with any of the other implementations, as appropriate. For example, an actuator component with restrictors but without ALA, as described with reference to Figures 1-6 and 8, may

comprise a buffer region or regions 150 at either end of the one or more piezoelectric strips 120 in the array direction 10, such that the actuator component comprises at least one opening 141 per fluid chamber 131 over a substantial portion of the array 130 of fluid chambers (for example in the main region 160). Other combinations may also be  
5 implemented.

It may further be understood that the cover parts do not need to be made from a solid material, but could instead be made from a flexible or highly viscous material which forms a barrier that can be shaped accordingly or a viscoelastic material, such as rubber, and  
10 equivalents.

It may be understood that the embodiments described herein may be used with both monolithic and chevron designs of actuator component. It may further be understood that layer(s) to form electrical tracks and coating layer(s) as described with reference to Figure  
15 2a to Figure 2d may be implemented in any of the embodiments described herein. Alternatively electrical tracks may be positioned at any other suitable location so as to enable chosen fluid chambers to receive electrical signals and be driven so as to eject droplets of fluid when desired. Coating layer(s) for electrical passivation and/or chemical protection and the like may also be applied at any suitable stage during the manufacturing process and  
20 in any suitable locations so as to perform their desired function(s).

CLAIMS

1. An actuator component for a droplet ejection head;

wherein said actuator component comprises a substrate and one or more strips of piezoelectric material fixedly attached to said substrate, a nozzle wafer, one or more inlet manifold channels, and one or more outlet manifold channels;

wherein said one or more strips of piezoelectric material comprise one or more layers of piezoelectric material, and

an array of fluid chambers defined within said one or more strips of piezoelectric material and extending in an array direction;

wherein each of said fluid chambers forms an open channel in the strip of piezoelectric material being open in the fluid chamber height direction and open at both ends in the fluid chamber extension direction;

wherein said actuator component further comprises a respective cover part on each side of said one or more strips of piezoelectric material, wherein each of said cover parts comprise a plurality of openings;

wherein the cover parts extend in said array direction and are fixedly attached to a side face of one of said strips of piezoelectric material and a portion of said substrate;

wherein said cover parts comprise at least one opening for every other fluid chamber over a substantial portion of the array;

wherein the fluid chambers are fluidically connected at one end to an inlet manifold channel via a plurality of openings so as to enable fluid to be supplied to selected ones of said fluid chambers through said openings, and a plurality of openings connect the array of fluid chambers to an outlet manifold channel; and

wherein said actuator component further comprises a nozzle wafer fixedly attached to the actuator component so as to fluidically seal said manifold channels, said openings and said array of fluid chambers.

2. An actuator component according to claim 1, further comprising electrical tracks and connections.

3. An actuator component according to claim 2, wherein at least a portion of said electrical tracks and connections are located between the substrate and said one or more cover parts and/or between said one or more strips of piezoelectric material and said one or more cover parts.

4. An actuator component according to claim 2 or claim 3, further comprising one or more coating layers, wherein said coating layers are located at least in part between the substrate and said one or more cover parts and/or between said one or more strips of piezoelectric material and said one or more cover parts so as to protect the electrical tracks and connections.

5

5. An actuator component according to any preceding claim, wherein said fluid chambers and said plurality of openings have a width in said array direction and wherein the width of the openings is less than or equal to the width of the fluid chambers.

10

6. An actuator component according to any preceding claim, wherein the fluid chambers are elongate in said fluid chamber extension direction which is at an angle to said array direction and wherein the length of the openings in the fluid chamber extension direction is less than or equal to the length of the fluid chambers.

15

7. An actuator component according to any preceding claim, wherein said fluid chambers and said plurality of openings have a height in the fluid chamber height direction, and wherein the height of the openings is less than or equal to the height of the fluid chambers.

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8. An actuator component according to any preceding claim, wherein said fluid chambers and said plurality of openings have a cross sectional area in said array direction, and wherein the cross sectional area of the openings is less than or equal to the cross sectional area of the fluid chambers.

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9. An actuator component according to any of claims 2 to 8, wherein the openings in the cover parts on each side of said one or more strips of piezoelectric material have the same length and/or the same width and/or the same height and/or the same cross-sectional area.

10. An actuator component according to any preceding claim, wherein said cover parts comprise at least one opening per fluid chamber over a substantial portion of the array.

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11. An actuator component according to any of claims 1 to 9 comprising dry fluid chambers, optionally wherein some or all of said dry fluid chambers are filled.

12. An actuator component according to any preceding claim, wherein there is a main region in the array of fluid chambers and a buffer region at either or both ends of the array of fluid chambers,

wherein the openings and/or the fluid chambers in the buffer region differ from those in the main region.

13. An actuator component according to any preceding claim, further comprising one or more ports, wherein the width of the openings increases with increasing distance from said one or more ports.

14. An actuator component according to any preceding claim, wherein said cover parts comprise one or more outer faces, and wherein at least one of said outer faces comprises a shaped profile.

15. An actuator component according to claim 14, wherein said shaped profile comprises a stepped profile or a chamfer or a concave or convex profile.

16. A droplet ejection head comprising an actuator component according to any of claims 1 to 15.

17. A method of manufacturing an actuator component for a droplet ejection head, wherein said method comprises the steps of:

- fixedly attaching one or more strips of piezoelectric material to a substrate;
- forming one or more arrays of fluid chambers in said one or more strips of piezoelectric material and extending in an array direction, wherein each of said fluid chambers forms an open channel in the strip of piezoelectric material being open in the fluid chamber height direction and open at both ends in the fluid chamber extension direction;
- forming a wafer that is conformal to said one or more strips of piezoelectric material and said substrate, wherein said wafer comprises one or more parts;
- fixedly attaching at least a part of said wafer to a portion of said substrate and at least a part of said wafer to a side face of said strips of piezoelectric material;
- removing material from said wafer and thereby forming a respective cover part on each side of said one or more strips of piezoelectric material which are fixedly attached to a face of one of said strips of piezoelectric material and at least a portion of said substrate; and
- selectively forming a plurality of openings in said cover parts wherein said cover parts comprise at least one opening for every other fluid chamber over a substantial portion of the array of fluid chambers;

wherein selectively forming the plurality of openings in the cover parts involves choosing the number of openings and/or the width and/or the length and/or the height and/or

the cross-sectional area of the openings depending on the type of actuator component that is required; and

wherein the fluid chambers are fluidically connected at one end to an inlet manifold channel via a plurality of openings so as to enable fluid to be supplied to selected ones of said fluid chambers through said openings and a plurality of openings connect the array of fluid chambers to an outlet manifold channel; and

- fixedly attaching a nozzle wafer to the actuator component so as to fluidically seal said manifold channels and said openings and said array of fluid chambers.

18. A method of manufacturing an actuator component for a droplet ejection head, wherein said method comprises the steps of:

- fixedly attaching one or more strips of piezoelectric material to a substrate;

- forming one or more arrays of fluid chambers in said one or more strips of piezoelectric material and extending in an array direction, wherein each of said fluid chambers forms an open channel in the strip of piezoelectric material being open in the fluid chamber height direction and open at both ends in the fluid chamber extension direction;

- forming a shape over said substrate and at least a part of said one or more strips of piezoelectric material;

- removing material from said shape and thereby forming a respective cover part on each side of said one or more strips of piezoelectric material which are fixedly attached to a face of one of said strips of piezoelectric material and to at least a portion of said substrate; and

- selectively forming a plurality of openings in said cover parts wherein said cover parts comprise at least one opening for every other fluid chamber over a substantial portion of the array of fluid chambers;

wherein selectively forming the plurality of openings in the cover part involves choosing the number of openings and/or the width and/or the length and/or the height and/or the cross-sectional area of the openings depending on the type of actuator component that is required; and

wherein the fluid chambers are fluidically connected at one end to an inlet manifold channel via the openings so as to enable fluid to be supplied to selected ones of said fluid chambers through said openings and the plurality of openings connect the array of fluid chambers to an outlet manifold channel; and

- fixedly attaching a nozzle wafer to the actuator component so as to fluidically seal said manifold channels and said openings and said array of fluid chambers.

19. A method according to claim 17 or claim 18, further comprising forming fills in parts/all of selected ones of said fluid chambers.

20. A method according to any of claims 17 to 19, further comprising forming a respective cover part on each side of said one or more strips of piezoelectric material.

21. A method according to any of claims 17 to 20, wherein forming said plurality of openings comprises selectively forming openings whose width in said array direction is less than or equal to the width of said fluid chambers,

and/or wherein the fluid chambers are elongate in a fluid chamber extension direction which is at an angle to said array direction and wherein the length of the openings in the fluid chamber extension direction is controlled to be less than or equal to the length of the fluid chambers,

and/or wherein the height of the openings is controlled to be less than or equal to the height of the fluid chambers,

and/or wherein the cross-sectional area of the openings is controlled to be less than or equal to the cross-sectional area of the fluid chambers.

22. A method according to any of claims 17 to 21, wherein forming said plurality of openings comprises forming fewer openings per cover part than there are fluid chambers.

23. A method according to any of claims 17 to 22, wherein selectively forming said plurality of openings comprises forming at least one opening per cover part per fluid chamber over a substantial portion of the array of fluid chambers.

24. A method according to claim 17 or claim 18, wherein the actuator component that is formed has:

an Alternate Line Active design by selectively forming at least one opening for every other fluid chamber over substantially all of the array of fluid chambers; and/or

a restrictor design by selectively forming openings wherein over substantially all of the array of fluid chambers the width of the openings is less than the width of the fluid chambers and/or the height of the openings is less than the height of the fluid chambers and/or the cross-sectional area of the openings is less than the cross-sectional area of the fluid chambers.

25. A method according to claim 24 wherein the Alternate Line Active design has at least one restrictor per open fluid chamber upstream and/or downstream of said open fluid chamber.

26. A method according to any of claims 17 to 25, wherein said method involves forming a number of sub-openings for each opening.

5 27. A method according to any of claims 17 to 26, further comprising shaping an outer surface or surfaces of the cover parts.

28. A method according to any of claims 17 to 27, further comprising forming electrical tracks and connections.

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