

1 INKJET PRINthead

2

3 Field of the invention

4

5 The invention relates to the field of inkjet printheads formed as a monolithic structure
6 on a substrate. Inkjet printheads eject printable fluids, such as coloured inks, materials
7 for additive printing etc.

8

9 Background to the invention

10

11 Conventional piezoelectric inkjet printheads with high densities of individual droplet
12 ejectors formed on the same substrate require large numbers of individual wire
13 connections, at least one per droplet. For a 1200dpi inkjet printhead, this may equate
14 to 1200 separate wire bonds to enable external, off-chip, connections

15

16 It has been proposed to provide an integrated piezoelectric inkjet printhead with CMOS
17 drive circuitry formed on a substrate and overlaid with a MEMS layer comprising
18 nozzles and MEMS piezoelectric transducers (WO2018/054917, McAvoy). This
19 enables the number of external, off-chip, connections to be greatly reduced.
20 Furthermore, the devices may be formed using conventional CMOS foundry processes
21 without additional assembly steps to join droplet ejector components.

22

23 It is desirable to maximise droplet ejector density, to minimise printing artefacts so that
24 adjacent nozzles are subject to consistent physical parameters (temperature, pressure

etc). As a result, on-chip wiring of individual droplet ejectors presents a technical problem and can limit maximum droplet ejector density. This is especially true in devices where nozzles are formed in the MEMS layer and ink chambers are defined at least in part by the substrate. In this case, the resulting holes through the substrate, and at least some of the surface area required for the piezoelectric transducers, are not available for routing electrical signals, limiting droplet ejector density.

The present invention addresses these issues and aims to provide a compact monolithic printhead which can be formed with a high density of droplet ejectors, typically using conventional CMOS foundry processes.

Summary of the invention

A printhead for ejecting one or more printable fluids, the printhead comprising a substrate;

the substrate defining a plurality of MEMS droplet ejectors for ejecting droplets of the one or more printable fluids and arranged in a lattice, each droplet ejector comprising a flexible diaphragm and a piezoelectric actuator to eject a droplet of a (respective) printable fluid through a nozzle by causing movement of the flexible diaphragm, each droplet ejector comprising at least one MEMS metallisation layer;

the substrate further defining CMOS control circuitry comprising at least one CMOS metallisation layer.

The substrate may comprise conductive connections in at least one said metallisation layer (i.e. at least one said MEMS metallisation layer and/or at least one said CMOS metallisation layer), extending from the CMOS control circuitry to each piezoelectric actuator to actuate the piezoelectric actuators.

The substrate may comprise conductive connections extending through the lattice in at least one said metallisation layer (i.e. at least one said MEMS metallisation layer and/or at least one said CMOS metallisation layer) to conduct actuator drive waveforms.

The substrate may comprise a plurality of bond pads in a discrete (e.g. single) zone (e.g. along a single edge) of the substrate.

1

2 The substrate may comprise one or more of:

- 3 (i) conductive connections in at least one said metallisation layer (i.e. at
4 least one said MEMS metallisation layer and/or at least one said CMOS
5 metallisation layer), extending from the CMOS control circuitry to each
6 piezoelectric actuator to actuate the piezoelectric actuators; and
- 7 (ii) conductive connections extending through the lattice in at least one said
8 metallisation layer (i.e. at least one said MEMS metallisation layer
9 and/or at least one said CMOS metallisation layer) to conduct actuator
10 drive waveforms, optionally and/or
- 11 (iii) a plurality of bond pads in a discrete (e.g. single) zone (e.g. along a
12 single edge) of the substrate.

13

14 The one or more printable fluids may comprise a plurality of printable fluids, typically at
15 least three or at least four different printable fluids. The printable fluids may be inks.
16 The inks may differ in colour. The printhead may be a multi-channel printhead. By this
17 we refer to a printhead with a plurality of different printable fluids and/or a plurality of
18 different lattices (droplet ejector zones), typically with separate printable fluid supplies.

19

20 The lattice may be a parallelogrammic lattice. The lattice may be a rhombic lattice, a
21 hexagonal lattice, a rectangular lattice (for example a square lattice) or an equilateral
22 triangular lattice. Thus, the plurality of MEMS droplet ejectors may be arranged in a
23 grid.

24

25 The lattice of MEMS droplet ejectors typically forms a droplet ejector zone of the
26 substrate. The droplet ejector zone typically comprises at least 100 droplet ejectors.
27 The droplet ejector zone is typically elongate. The droplet ejector zone typically has a
28 length and a width. The droplet ejector zone may be rectangular. The droplet ejector
29 zone may be a parallelogram. Typically, the ratio of the length to the width of the droplet
30 ejector zone is at least 5, or at least 10, or at least 20. By the length and width we refer
31 to the length and width of the smallest area rectangle which would wholly encompass
32 the droplet ejector zone.

33

34 Typically, the lattice comprises a plurality of rows of MEMS droplet ejectors extending
35 across the width of the lattice. Typically, there are more rows (which extend across the
36 width) than there are MEMS droplet ejectors in any row. Typically there are at 4 to 16,

1 or more typically 8 to 12 MEMS droplet ejectors in each row (which extends across the
2 width).

3

4 Typically the lattice comprises more than 50 rows (which are typically parallel to each
5 other). The rows may be aligned parallel to the width of the droplet ejector zone.
6 However, this is not essential, for example in the case of a parallelogramic lattice, the
7 rows will not be aligned parallel to the width of the droplet ejector zone but at a slight
8 angle. Typically, the rows extend at an angle of between 45° and 135° to the length of
9 the droplet ejector zone, or between 30° and 120° to the length of the droplet ejector
10 zone, or between 15° and 105° to the length of the droplet ejector zone.

11

12 It may be that the substrate comprises (i) conductive connections (actuation conductive
13 connections) in at least one said metallisation layer, extending from the CMOS control
14 circuitry to each piezoelectric actuator to actuate the piezoelectric actuators.

15

16 In some embodiments, there are one or more separate individual conductive
17 connections extending from the CMOS control circuitry to each piezoelectric actuator
18 to actuate each piezoelectric actuator individually. In other embodiments, one or more
19 conductive connections to actuate the actuators are connected each of a plurality of
20 piezoelectric actuators to actuate each piezoelectric actuator however in this case the
21 CMOS control circuitry is typically configured to address control signals individually to
22 each piezoelectric actuator.

23

24 Typically, the length of the actuation conductive connections, between the CMOS
25 control circuitry and the piezoelectric actuators in a group of piezoelectric actuators is
26 consistent. The actuation conductive connections are of similar length, thickness and
27 breadth so that they are affected to a similar extent by voltage droop, parasitic
28 capacitance, antenna effects etc.

29

30 It may be that the length of the conductive connections to actuate the piezoelectric
31 actuators, between the CMOS control circuitry and the piezoelectric actuators within a
32 droplet ejector zone, is consistent.

33

34 Typically, the length of the conductive connections to actuate the piezoelectric
35 actuators, between the CMOS control circuitry (for example, an ejection transistor) and
36 the piezoelectric actuators in a droplet ejector zone varies by no more than 1cm,
37 preferably no more than 0.1cm. Typically, the length of the conductive connections to

1 actuate the piezoelectric transducers, between the CMOS control circuitry and the
2 piezoelectric actuators in a droplet ejector zone varies by no more than 10 times the
3 spacing between droplet ejectors along a row of droplet ejectors. Typically, the
4 substrate is elongate with a length and width and the length of the conductive
5 connections to actuate the piezoelectric transducers, between the CMOS control
6 circuitry and the piezoelectric actuators in a droplet ejector zone varies by no more
7 than 20%, or no more than 10% of the width of the substrate. The droplet ejector zone
8 typically comprises at least 8 droplet ejectors. The droplet ejectors of the droplet ejector
9 zone typically eject the same one printable fluid of a plurality of printable fluids.

10
11 Typically, the conductive connections to actuate the piezoelectric actuators comprise
12 metal wires which extend from the CMOS control circuitry in one or more CMOS
13 metallisation layers, through a connection to one or more MEMS metallisation layers
14 adjacent the respective piezoelectric actuator, and through the one or more MEMS
15 metallisation layers to an electrode of the MEMS piezoelectric actuator.

16
17 The CMOS metallisation layers are metallisation layers which connect CMOS devices
18 in the substrate and which are formed as part of a CMOS manufacturing process. The
19 MEMS metallisation layers are metallisation layers which are formed (on top of the
20 CMOS metallisation layers) and used for the purpose of operating the MEMS device.
21 (In the present invention, the MEMS metallisation layers may also comprise additional
22 conductors, for example conductive connections to conduct actuator drive waveforms).
23 One or more of the piezoelectric transducer, the electrodes and the MEMS
24 metallisation layers may comprise gold. Gold is excluded from CMOS manufacturing
25 facilities.

26
27 The lattice of MEMS droplet ejectors may form a droplet ejector zone of the substrate,
28 the droplet ejector zone being elongate with a length and a width and with opposite
29 long sides along the length, wherein the conductive connections to actuate the
30 actuators extend into the lattice, from one or two of the opposite long sides of the
31 droplet ejector zone.

32
33 Typically, the conductive connections extend into the lattice with a length which is less
34 than 1.5 times and typically less than 1.2 times the width of the droplet ejector zone. In
35 some embodiments, the conductive connections extend into the lattice with a length
36 which is less than the width of the droplet ejector zone

37

1 The CMOS control circuitry may comprise a plurality of drive transistors at least one of
2 which is connected directly to at least one electrode of the piezoelectric transducer of
3 each MEMS droplet ejector by a said conductive connection to actuate the
4 piezoelectric actuators, without intervening transistors, wherein the plurality of drive
5 transistors are arranged in at least one row adjacent the one or two opposite long sides
6 of the droplet ejector zone.

7
8 It may be that the conductive connections to actuate the piezoelectric actuators extend
9 into the lattice between rows of MEMS droplet ejectors.

10
11 Typically, the conductive connections to actuate the piezoelectric actuators extend into
12 the lattice between rows of MEMS droplet ejectors from one or both opposite long
13 sides. Typically, conductive connections to actuate the piezoelectric actuators extend
14 widthwards into the lattice between rows of MEMS droplet ejectors.

15
16 This arrangement ensures that MEMS droplet ejectors within the same row (parallel to
17 the width) receive control signals from the control circuitry at very similar times. This
18 improves print quality and/or reduces control complexity.

19
20 Typically, the aspect ratio of the length to the width (of the lattice / droplet ejector zone)
21 is at least 5 or at least 10 or at least 20.

22
23 It may be that conductive connections to actuate the piezoelectric actuators extend into
24 the lattice, from one or both long sides. Where the conductive connections to actuate
25 the piezoelectric actuators extend into the lattice from both long sides, along the width.

26
27 It may be that the rows of piezoelectric actuators between which the conductive
28 connections to actuate the piezoelectric transducers extend, are aligned at an angle of
29 at least 45° and typically at least 60° or at least 75° to the length of the droplet ejector
30 zone.

31
32 It may be that the actuator drive waveforms comprise pulses with portions at each
33 polarity. Thus, the direction of the potential difference across each piezoelectric
34 actuator reverses twice within each droplet ejection.

35
36 It may be that the CMOS control circuitry is configured to determine, for each MEMS
37 droplet ejector, for each of a plurality of ejection cycles, whether or not that MEMS

1 droplet ejector should eject a droplet, wherein the conductive connections to actuate
2 the actuators are connected to ejector switches (typically latches) associated with each
3 MEMS droplet ejector to thereby control whether each individual MEMS droplet ejector
4 does or does not eject a droplet.

5
6 Thus, a determination whether each MEMS droplet ejector should eject a droplet is
7 made in the CMOS control circuitry (typically in response to digital image data received
8 through a digital interface, typically the one or more bond pads). This avoids a
9 requirement for large numbers of individual conductive connections to control circuitry
10 which is external to the substrate, thereby reducing the difficulty of connecting the
11 substrate. Typically a decision is made for each MEMS droplet ejector for each of the
12 plurality of ejection cycles. An ejection cycle may comprise a plurality of phases during
13 each of which a different subset of MEMS droplet ejectors eject printable fluid, if
14 selected.

15
16 The substrate may comprise (ii) conductive connections extend through the lattice in
17 at least one said metallisation layer to conduct actuator drive waveforms, to connect
18 the MEMS droplet ejectors to one or more sources of actuator drive waveforms.

19
20 It may be that the conductive connections connect different groups of MEMS droplet
21 ejectors to different ones of a plurality of sources of actuator drive waveforms, to
22 thereby relay different actuator drive waveforms to different groups of MEMS droplet
23 ejectors.

24
25 Typically the MEMS droplet ejectors comprise a plurality of spatially separate MEMS
26 droplet ejector zones, each comprising a lattice of MEMS droplet ejectors and each
27 MEMS droplet ejector in the same droplet ejector zone receives the same actuator
28 drive waveform. Typically, for at least two, or at least four, different droplet ejector
29 zones, the droplet ejectors in each zone receive a different actuator drive waveform.
30 Typically, the droplet ejectors in each zone receive printable fluid from the same
31 source. Thus, droplet ejectors which eject different printable fluids may receive different
32 actuator drive waveforms, while those droplet ejectors which eject the same printable
33 fluid may be located in the same droplet ejector zone and receive the same actuator
34 drive waveform. Thus, the actuator drive waveforms can be customised depending on
35 the physical properties of each printable fluid.

36

1 The sources of actuator drive waveforms may comprise one or more actuator drive
2 waveform generators. The sources of actuator drive waveforms may comprise one or
3 more interfaces, such as bond pads of the printhead substrate, typically the said
4 plurality of bond pads, for receiving actuator drive waveforms from a source which is
5 external to the substrate. The external source may for example be one or more actuator
6 drive waveform generators which are not formed on the substrate, and typically are
7 separate to the printhead but located within print apparatus, such as a printer, which
8 also comprises the printhead.

9
10 It may be that the droplet ejector zone has a length and a width, and with opposite long
11 sides along the length, wherein the conductive connections to conduct actuator drive
12 waveforms extend into the lattice, from one or two of the opposite long sides of the
13 droplet ejector zone.

14
15 It may be that conductive connections to conduct actuator drive waveforms extend into
16 the lattice, from one or both opposite long sides. It may be that conductive connections
17 to conduct actuator drive waveforms extend into the lattice between rows of MEMS
18 droplet ejectors, from one or both opposite long sides. It may be that conductive
19 connections to conduct actuator drive waveforms extend widthwards into the lattice,
20 between rows of MEMS droplet ejectors.

21
22 It may be the rows of piezoelectric actuators between which the conductive
23 connections to conduct actuator drive waveforms extend, are aligned at an angle of at
24 least 45°, and typically at least 60° or at least 75° to the length of the droplet ejector
25 zone.

26
27 It may be that the substrate defines a plurality of elongate droplet ejector zones and
28 the conductive connections to conduct actuator drive waveforms comprise a plurality
29 of separate buses, wherein for one or more of the elongate droplet ejector zones,
30 conductors which are part of the bus to conduct actuator drive waveforms to that zone
31 extends across the width of one or more further droplet ejector zones.

32
33 Thus the conductive connections to conduct actuator drive waveforms do not need to
34 extend around the (short) edges of each droplet ejector zone, reducing their length and
35 enabling more substrate surface area to be used than if they instead extended around
36 the (short) edge of each droplet ejector zone.

37

1 It may be that the substrate comprises (iii) a plurality of bond pads in a single discrete
2 zone of the substrate.

3

4 The substrate may comprise a bond pad zone, comprising a plurality of bond pads,
5 which is spatially separate from the plurality of MEMS droplet ejectors and typically
6 also spatially separate from the CMOS control circuitry. There may be only a single
7 bond pad zone. The bond pad zone may be elongate and arranged along a single edge
8 of the substrate. Typically the substrate is elongate with opposing long edges, with
9 short edges therebetween and the bond pad zone is arranged along a long edge.
10 However, in some embodiments, the bond pad zone may be on a short edge. There
11 may be two bond pad zones which are elongate and typically also arranged along
12 opposite long sides of the substrate. The bond pads within a or the bond pad zone may
13 be spaced apart along a straight line.

14

15 The substrate may comprise, in total, fewer than 75 or even fewer than 50 external
16 electrical connections. The ratio of individually controllable MEMS droplet ejectors to
17 external electrical connections may be greater than 1, greater than 10 or in some
18 embodiments greater than 100. This is enabled by the CMOS control circuitry and
19 reduces the complexity of the wiring connections to the substrate in comparison to
20 printing apparatus requiring a separate electrical connection for each individually
21 controllable MEMS droplet ejector on the substrate.

22

23 It may be that one or more conductive connections for actuator drive signals is
24 configured to switchedly provide a potential to 100 or more, or even 1000 or more
25 droplet ejectors. It may be that the conductive connections extending from the CMOS
26 drive circuitry to the piezoelectric actuators to actuate the piezoelectric actuators each
27 provide a potential to 10 or fewer, 4 or fewer, or only one piezoelectric actuator. Thus,
28 they may require a much lower cross section of conductive metal than the conductive
29 connections for actuator drive signals.

30

31 It may be that there are no transistors within the lattice of MEMS droplet ejectors.

32

33 However, it may be that, for at least the majority of the plurality of MEMS droplet
34 ejectors, an ejector switch comprising one or more CMOS transistors formed on the
35 substrate, is located within the lattice in electronic communication with one or more
36 said conductive connections (conductive connections to actuate the piezoelectric
37 actuators and/or conductive connections to conduct actuator drive waveforms and/or

1 conductive connections to connect each of the MEMS droplet ejectors to two or more
2 different fixed voltages), to controllably cause a potential difference to be applied to the
3 electrodes of the piezoelectric actuator of the respective MEMS droplet ejector and
4 cause printable fluid ejection by the MEMS droplet ejector. The ejector switch typically
5 comprises a latch.

6
7 It may be that the ejector switch is configured to selectively route an actuator drive
8 waveform (voltage and/or current) to the respective piezoelectric transducer, the
9 actuator drive waveform being received through one or more said conductive
10 connections in at least one metallisation layer.

11
12 Thus, the power electronics required to generate the current for the piezoelectric
13 transducers can be located elsewhere, and the associated heat generated elsewhere.
14 In some embodiments, the ejector switch requires only to switch the actuator drive
15 waveform, reducing power consumption on the substrate, within the lattice.

16
17 Typically, the CMOS control circuitry is located in one or more discrete zones of the
18 substrate, separate to the bonds pads and MEMS droplet ejectors.

19
20 Nevertheless, in some embodiments the ejector switches may be located within the
21 lattice for at least the majority of the plurality of MEMS droplet ejectors. In other
22 embodiments, one or more transistors which function as ejectors switches for individual
23 respective MEMS droplet ejectors are located within the CMOS control circuitry. Thus,
24 it may be that there are no transistors, or at least fewer transistors than MEMS droplet
25 ejectors, within the lattice of MEMS droplet ejectors.

26
27 It may be that each MEMS droplet ejector includes a hole through the substrate for
28 ejection of printable fluid.

29
30 Thus, the substrate comprises a plurality of holes, each associated with a
31 corresponding one of the MEMS droplet ejectors. The holes typically form a lattice. The
32 holes are typically nozzles for the MEMS droplet ejectors. Typically each nozzle is in
33 fluid communication with a printable fluid chamber defined at least in part by the
34 substrate.

35

1 Because each MEMS droplet ejector includes a hole through the substrate, the surface
2 area of substrate available for conductive connections is limited. Typically, the
3 conductive connections extend in between rows of holes.

4
5 Typically, each flexible diaphragm extends around a corresponding hole. The
6 conductive connections may extend in between flexible diaphragms, without overlap
7 with the flexible diaphragms. The conductive connections may extend in between
8 holes, without overlap with the central 50% by surface area of the flexible diaphragms.

9
10 It may be that, in at least a region of the substrate (typically at least a region of the
11 substrate within the lattice of droplet ejectors, for example adjacent each droplet
12 ejector), the one or more MEMS metallisation layers overlie the one or more CMOS
13 metallisation layers.

14
15 One or more MEMS metallisation layers may be formed directly over the one or more
16 CMOS metallisation layers.

17
18 It may be that one or more CMOS metallisation layers is integrated with one or more
19 MEMS metallisation layers, for example, at an interface of the CMOS control circuitry.
20 Thus, one or more CMOS metallisation layers and one or more metallisation layers
21 may be formed concurrently.

22
23 One or more CMOS metallisation layers may be electrically connected to one or more
24 MEMS metallisation layers.

25
26 One or more insulation layers may be formed between the one or more CMOS
27 metallisation layers and the one or more MEMS metallisation layers. Typically, the said
28 one or more insulation layers is thicker than the insulation layers between the CMOS
29 metallisation layers. This provides additional electrical insulation and decreases
30 parasitic capacitance between metal wiring layers.

31
32 It may be that the substrate further comprises conductive connections extending
33 through the lattice in at least one metallisation layer to connect each of the MEMS
34 droplet ejectors (typically the ejector switch of each MEMS droplet ejector) to two or
35 more different fixed voltages, wherein the CMOS control circuitry (typically the ejector
36 switch associated with each MEMS droplet ejector) is configured to selectively connect
37 at least one electrode of the piezoelectric actuator of the respective droplet ejector to

1 each of a plurality of the two or more different fixed voltages in turn, responsive to
2 control signals from the CMOS control circuitry.

3
4 It may be that the droplet ejector zone has a length and a width, and with opposite long
5 sides along the length, wherein the conductive connections to connect each of the
6 MEMS droplet ejectors to two or more different fixed voltages extend into the lattice,
7 from one or two of the opposite long sides of the droplet ejector zone.

8
9 It may be that conductive connections to connect each of the MEMS droplet ejectors
10 to two or more different fixed voltages extend into the lattice, from one or both opposite
11 long sides. It may be that conductive connections to connect each of the MEMS droplet
12 ejectors to two or more different fixed voltages extend into the lattice between rows of
13 MEMS droplet ejectors, from one or both opposite long sides. It may be that conductive
14 connections to connect each of the MEMS droplet ejectors to two or more different
15 fixed voltages extend widthwards into the lattice, between rows of MEMS droplet
16 ejectors.

17
18 It may be the rows of piezoelectric actuators between which the conductive
19 connections to connect each of the MEMS droplet ejectors to two or more different
20 fixed voltages extend, are aligned at an angle of at least 45° and typically at least 60°
21 or at least 75° to the length of the droplet ejector zone.

22
23 It may be that the substrate defines a plurality of elongate droplet ejector zones and
24 the conductive connections to connect each of the MEMS droplet ejectors to two or
25 more different fixed voltages comprise a plurality of separate buses, wherein for one or
26 more of the elongate droplet ejector zones, conductors which are part of the bus to
27 conduct actuator drive waveforms to that zone extends across the width of one or more
28 further droplet ejector zones.

29
30 Thus the conductive connections to connect each of the MEMS droplet ejectors to two
31 or more different fixed voltages do not need to extend around the (short) edges of each
32 droplet ejector zone, reducing their length and enabling more substrate surface area
33 to be used than if they instead extended around the (short) edge of each droplet ejector
34 zone.

35

1 It may be that one or more conductive connections to connect each of the MEMS
2 droplet ejectors to two or more different fixed voltages is configured to switchedly
3 provide a potential to 100 or more, or even 1000 or more droplet ejectors.

4
5 It may be that the ejector switch is configured to selectively connect a respective
6 piezoelectric transducer to two or more (or three or more) different fixed voltages in
7 turn to actuate a droplet ejection, the piezoelectric transducer being connected to the
8 different fixed voltages through one or more said conductive connections in at least
9 one metallisation layer.

10
11 It may be that the printhead comprises a first plurality of conductive connections and a
12 second plurality of conductive connections, wherein the one of the first and second
13 plurality of conductive connections comprises the conductive connections to actuate
14 the piezoelectric actuators and the other of the first and second plurality of conductive
15 connections comprises conductive connections to conduct droplet ejector waveforms
16 or a plurality of different potentials, and wherein at one or more locations within the
17 lattice, at least one first conductive connection and at least one second conductive
18 connection both extend. Typically, they extend in different metallisation layers.

19
20 The said at least one first and at least one second conduction connection may be
21 parallel. The said at least one first and at least one second conduction connection may
22 cross each other.

23
24 Typically, the at least one conductive connection to conduct a droplet ejector waveform
25 is located within a MEMS metallisation layer and at least one conductive connection to
26 actuate the piezoelectric actuators is located within a CMOS metallisation layer.

27
28 Typically, one of the first and second plurality of conductive connections extends
29 through one or more MEMS metallisation layers and the other of the first and second
30 plurality of conductive connections extends through one or more CMOS metallisation
31 layers.

32
33 It may be that conductors to conduct actuation signals to the droplet ejectors extend
34 between rows of droplet ejectors such that they overlap but are located in different
35 metallisation layers, e.g. different CMOS metallisation layers. This enables a larger
36 number of droplet ejectors to be individual addressed from one side of a droplet ejector
37 zone.

1

2 It may be that, at one or more locations within the lattice, at least one conductive
3 connection to actuate the piezoelectric actuators and at least one conductive
4 connection to conduct a droplet ejector waveform, extend (typically in parallel) between
5 the same adjacent rows of droplet ejectors.

6

7 It may be that the lattice comprises at least a first, a second and a third row of MEMS
8 droplet ejectors (typically without other rows in between) wherein a plurality of (and
9 typically at least four) conductive connections extend between droplet ejectors of the
10 first and second row to different respective droplet ejectors along the length of the
11 second row, typically wherein a plurality of (and typically at least four) conductive
12 connections extend between droplet ejectors of the second and third row to different
13 respective droplet ejectors along the length of the second row.

14

15 The plurality of (typically at least four) conductive connections extending between rows
16 of droplet ejectors to different respective droplet ejectors may extend through the same,
17 or different, metallisation layers.

18

19 It may be that the CMOS control circuitry comprises one or more first zones and one
20 or more second zones, wherein the substrate comprises one or more isolation features
21 separating the first and second zones, wherein the one or more first zones comprise
22 transistors which process digital signals and the one or more second zones comprise
23 drive transistors which provide potentials directly to the electrodes of piezoelectric
24 actuators, wherein the second zone operates at at least double the maximum potential
25 of the first zone.

26

27 It may be that the CMOS control circuitry is formed on a first surface of the substrate
28 and wherein the flexible diaphragms, piezoelectric actuators and MEMS metallisation
29 layers are also formed on the first surface of the substrate.

30

31 The first surface of the substrate typically comprises a nozzle-forming layer which
32 comprises the flexible diaphragms and piezoelectric actuators.

33

34 It may be that the substrate defines a plurality of adjacent droplet ejector zones which
35 are elongate having a length and a width and which are spaced apart orthogonally to
36 their length, wherein between each adjacent droplet ejector zone there is provided at
37 least one CMOS circuitry zone which is also elongate and aligned in the same

1 orientation as the droplet ejectors zones, the CMOS circuitry zone including at least
2 one CMOS metallisation layer, wherein conductive connections extend from the CMOS
3 circuitry into adjacent droplet ejector zones to actuate piezoelectric actuators.

4
5 Typically, the substrate is elongate (typically rectangular) and the droplet ejector zones
6 have a length and width aligned with the length and width of the substrate.

7
8 It may be that the at least one CMOS circuitry zone comprises both a higher and a
9 lower voltage region, the lower voltage region comprising one or more digital logic
10 gates, the higher voltage region comprising ejection transistors which are directly
11 connected to the piezoelectric transducers of respective droplet ejectors.

12
13 Typically, the higher and lower voltage regions are separate by an isolation feature in
14 the substrate.

15
16 By higher and lower voltage regions we refer to the relative voltage during operation.

17
18 It may be that one or more conductive connections for actuator drive waveforms extend
19 widthwise across one or more droplet ejector zones and connect to a higher voltage
20 region of a CMOS circuitry zone.

21
22 The invention extends in a second aspect to printing apparatus comprising a printhead
23 according to the first aspect of the invention.

24
25 According to a third aspect of the invention there is provided a method of forming a
26 printhead according to any one preceding claim, comprising the steps of:
27 forming a lattice of apertures through a substrate, each aperture to at least in
28 part define a fluid chamber of a droplet ejector;
29 forming the CMOS control circuitry, including at least one CMOS metallisation
30 layer, on a first surface of the substrate;
31 forming a MEMS layer, comprising flexible diaphragms, piezoelectric actuators
32 and at least one MEMS metallisation layer, on the first substrate of the
33 substrate, to thereby form the plurality of droplet ejectors;
34 whereby each droplet ejector is conductively connected to the CMOS control
35 circuitry through at least one said metallisation layer.

36

1 The method may comprise forming an insulating layer over the CMOS control circuitry
2 before the step of forming at least one MEMS metallisation layer.

3
4 The MEMS layer may have holes therein. The holes may function as the nozzles of the
5 droplet ejectors.

6
7 Description of the Figures

8
9 An example embodiment of the present invention will now be illustrated with reference
10 to the following Figures in which:

11
12 Figure 1 is a plan view of an integrated inkjet printhead;

13
14 Figure 2 is a schematic diagram of control circuitry within and external to the printhead;

15
16 Figure 3 is a plan view of electrode drive conductors extending through the lattice of
17 droplet ejectors;

18
19 Figure 4 is a cross-section through a region of integrated inkjet printhead;

20
21 Figure 5 is a plan view of rows of 8 actuators being connected to respective drive
22 circuitry on either side of those rows, through electrode drive conductors which extend
23 into the lattice from opposite long sides;

24
25 Figure 6 is a plan view of an embodiment in which rows of 8 actuators are connected
26 to drive circuitry arranged along a single side of the rows;

27
28 Figure 7 is a plan view of selected components from a portion of the printhead at the
29 left side of Figure 1;

30
31 Figures 8 and 9 are plan views of electrical connections extending across a lattice of
32 droplet ejectors;

33
34 Figure 10 is a plan view of conductors extending across a plurality of lattices of droplet
35 ejectors of different channels;

36
37 Figure 11 is a cross-section through a printhead substrate according to the invention;

Figure 12 is a cross-section through a printhead substrate according to Figure 3 along a lengthwise cross-section extending between two actuator drive waveform conductors;

Figures 13 and 14 correspond to Figures 3 and 11 for an alternative cross-section through a substrate;

Figure 15 is a flow chart of a method of manufacturing a printhead module.

Detailed Description of an Example Embodiment

Figure 1 is a plan view showing the layout of an integrated inkjet printhead 100. The printhead is formed on a single semiconductor substrate 102 and is elongate with opposite long edges 104 parallel to its length 106 and opposite short edges 103 parallel to its width 108. A bond pad zone 110 comprising a plurality of bond pads 112 is arranged along part of a single long edge. The substrate has a plurality of elongate zones of integrated droplet ejectors 114A, 114B, 114C, 114D, each relating to a different channel and aligned with the long edges of the substrate and so extending lengthwise. Each zone comprises droplet ejectors having the same printable fluid supply. In this example, each zone of integrated droplet ejectors has a different colour printable fluid supply although the invention is applicable to multi-channel devices with single colour or single type printable fluid supplies. Within each zone, the droplet ejectors are arranged in a lattice (a repeating array of points e.g. a rhombic lattice, a square lattice, a hexagonal lattice, a rectangular lattice, a parallelogrammic lattice, an equilateral triangular lattice). In this example, the droplet ejectors are arranged in a parallelogrammic lattice having columns extending parallel to the length of the substrate (lengthwise) and rows extending across the width of the lattice, at a slight angle to the width of the lattice (widthwise). Rows of droplet ejectors extend widthwise across each zone of droplet ejectors, at a small angle to the long edges and to the length of the droplet ejector zones. This parallelogrammic arrangement provides droplet ejectors at a wide range of longitudinal positions increasing maximum print density.

The substrate is a semiconductor substrate with CMOS control circuitry formed thereon. The CMOS control circuitry comprises central control circuitry 120 (master data path circuit) which carries out calculations and determines signal routing, and also

1 drive circuitry 122, comprising at least one CMOS drive transistor for each droplet
2 ejector. The drive circuitry functions as latches and provides wired connections to the
3 electrodes of a piezoelectric actuator in each droplet ejector. Elongate zones of drive
4 circuitry 122 are arranged along and also interposed between opposite long sides of
5 each zone of droplet ejectors and are configured to controllably actuate the droplet
6 ejectors in each zone of droplet ejectors, such that individual rows of droplet ejectors
7 are actuated by drive transistors at either end of the row, using conductive connections
8 240 extending into the lattice of droplet ejectors from opposite long sides.

9
10 Figure 2 is a schematic diagram of the control circuitry for a printhead assembly. In
11 this example, control of the printhead is distributed between a machine controller 220,
12 which is separate to the substrate, and the control circuitry (e.g., CMOS circuit) 120,
13 122A-D on the substrate 102. They are connected in part by conductors extending
14 through a single or multiple flexible cable interconnects 218.

15
16 Individual piezoelectric actuators 320 within droplet ejectors are controlled by the
17 application of potentials to their electrodes 340, 342. These potentials are typically
18 time-varying in the form of an actuator drive waveform which typically repeats for each
19 droplet ejection cycle. The machine controller comprises at least a processor 200, such
20 as a microprocessor or microcontroller which has memory 202 storing relevant data
21 and program code. A wired or wireless electronic interface 204 receives input data
22 from an external device driver. One skilled in the art will appreciate that the machine
23 controller may be distributed between a number of separate components or functional
24 modules, such as one component which converts an image into a pixelated pattern for
25 printing using a dither matrix, for example, and a separate component which converts
26 the pixelated pattern into a print pattern for the different nozzles.

27
28 The machine controller may comprise at least one waveform generator and a voltage
29 amplifier 208 which provides a continuous pattern of actuator control pulses to the
30 printhead through one or more drive signal conductors 210. A ground conductor 212
31 also extends from the machine controller to the substrate. (Ground connections on
32 the substrate are not shown for clarity). The processor 200 generates digital control
33 signals 214 typically as a serial bus, and also transmits clock signals 216 to the
34 printhead which serve to synchronise printing with movements of the printhead. The
35 connector also provides voltage levels associated with the operational voltage of
36 CMOS control electronics.

37

1 On the substrate 100, bond pads 112 are connected to the conductors of the flexible
2 connector and signals are routed from the bond pads through metallisation layers to
3 the CMOS control circuit 120 and from the CMOS control circuit to the electrodes 320,
4 340 which actuate individual piezoelectric bodies 342 within respective droplet
5 ejectors. The received signals includes both digital control signals encoding image
6 information and the analogue actuator control pulses which are conducted through
7 actuator drive waveform conductors 250.

8
9 The control circuit 120 on substrate 102 extends to the drive circuitry 122 which
10 comprises ejection switch circuit 220, including ejection transistors having outputs
11 which are in direct electrical connection with the electrodes 340, 342 (i.e. without a
12 further intervening switching semiconductor junction) through electrode drive
13 conductors 240, being conductive connections directly connected to the electrodes.
14 The ejection switch circuit selectively switches the actuator control pulse signals
15 received through conductor 250 to apply these pulses signals to the respective
16 electrodes through electrode drive conductors 240. If one of the electrodes remains
17 connected to ground, the ejection switch circuit may be as simple as a single transistor
18 per actuator, or a single transistor per electrode to switch the signal applied to that
19 electrode and there may be a single electrode drive conductor 240 extending to the
20 individual piezoelectric actuator, although in the example shown there are two
21 conductors extending to each individual piezoelectric actuator, one per electrode.

22
23 The ejection switch circuit does not carry out power amplification. Instead it switches
24 the actuator control pulses, determining whether each pulse is relayed to the respective
25 actuator or not, for each pulse. Voltage amplification is carried out in the machine
26 controller by amplifier 208.

27
28 The ejection switch circuit is controlled by latch and shift transistors 222, which receive
29 and store digital data from a control circuit 224 which processes received data, for
30 example converting received serial data, storing these in registers 226 and using the
31 received data to determine which actuators are to actuate during each successive
32 actuator firing events. The control circuit 228 also stores trim data used to customise
33 the precise timing of voltage switching for each actuator, which is typically determined
34 during a calibration step on set-up, and may store configuration data 230 which
35 indicates the physical layout of nozzles, security information and or nozzle actuation
36 count history information. The control circuit 224 also receives data from sensors 232,
37 234, 236, some of which are associated with individual actuators, for example nozzle

1 fill levels sensors, and some of which sense parameters relevant to the function of the
2 printhead as a whole, for example temperature sensors.

3
4 Figure 3 is a cross-section through a region of integrated inkjet printhead 100, which
5 comprises a silicon substrate 102, having an insulator layer 302 (thus being a silicon-
6 on-insulator or silicon-on-insulator-on-silicon substrate). Integrated CMOS circuitry
7 120, 122 is formed in the first surface 304 of the silicon substrate with overlying CMOS
8 metallisation layers 306 and intervening passivation layers 308, such as SiO₂, SiN,
9 SiON. The person skilled in the art will appreciate that a CMOS circuit comprises both
10 doped regions of the substrate and the metallisation layers within which
11 interconnections are formed on the first surface of the substrate. The number of CMOS
12 metallisation layers is variable but will typically be at least three.

13
14 The CMOS circuitry is divided into the central control circuitry 120 which is digital and
15 operates at a standard CMOS digital logic voltage, such as 5V and the drive circuitry
16 122 which processes digital logic signals and switches analogue signals, particularly
17 the actuator control pulse signals and so operates at a higher voltage than the central
18 control circuitry. The CMOS circuits operating at the two different voltage levels are
19 separated by deep trench isolation (DTI) barriers 310. A cross connector 312 extends
20 across a DTI barrier to connect the ejection transistors in the drive circuitry 112 to the
21 electrode drive conductors 240 which extend into the lattice of droplet ejectors. Bond
22 pads 112 are formed on the substrate and communicate predominantly with the central
23 control circuitry through paths in the CMOS metallisation layers to process digital
24 signals, however one or more bond pads conduct the analogue actuator control pulse
25 signals to the drive circuitry.

26
27 The printhead further comprises piezoelectric actuators comprising a piezoelectric
28 body 320 which in this example is formed of AlN or ScAlN but may be formed of another
29 suitable piezoelectric material which is processable at a temperature of below 450°C,
30 to enable it to be deposited without damage to the underlying CMOS structures. The
31 piezoelectric actuator 320 forms a diaphragm with layers of materials such as silicon,
32 silicon oxide, silicon nitride or derivatives thereof and has a passivation layer 322
33 (sometimes referred to as a nozzle defining layer 322) which prevents applied electrical
34 potentials from contacting fluid. Thus a MEMS layer, 320, 322, 323, 340, 342, 350,
35 352, 362 overlies CMOS layer 120, 122, 306, 307, 312 with the MEMS layers and
36 CMOS layers being formed integrally.

37

1 The CMOS metallisation layers 306 include interconnects, conducting external signals,
2 signals with the central control circuitry, and within the drive circuitry. The drive circuitry
3 is configured to apply a potential difference in use to piezoelectric actuator electrodes
4 340 and 342, through the CMOS metallisation layers 306 and a connection to one or
5 more MEMS metallisation layers 350, adjacent the droplet ejectors. In this example,
6 the MEMS metallisation layer shown connects to the CMOS metallisation layers
7 through a via 352 extending through a passivation layer 354 between the MEMS
8 structures and the CMOS metallisation layers. The electrode drive conductor 240
9 extending to one of the electrodes 342 shown in Figure 4 is formed in part by MEMS
10 metallisation layer 350 and conductive tracks 307 in CMOS metallisation layers.

11

12 The piezoelectric actuator 320 and passivation layers 322, 323, 354 defines a wall of
13 a fluid chamber 360 which receives print agent, such as ink (in the case of an inkjet
14 printer) or another printable fluid (for example in the case of an additive manufacturing
15 printer) through a conduit (not shown). In operation, the piezoelectric actuator flexes
16 when a droplet ejection voltage waveform is applied and ejects fluid through a
17 respective nozzle 344.

18

19 It can be seen that the semiconductor cross-section comprises distinct zones. Zone
20 370 comprises both CMOS and MEMS metallisation (and metal wiring) and CMOS
21 transistors. Zone 372 comprises only MEMS metallisation, without CMOS metallisation
22 or transistors. Zone 374 comprises both CMOS and MEMS metallisation (and metal
23 wiring), but no CMOS transistors.

24

25 This actuator configuration is compact and energy efficient but the presence of holes
26 (the chambers and nozzles) and the flexible regions (the piezoelectric actuators) limits
27 the surface area which is available to route conductive connections and therefore can
28 limit nozzle density.

29

30 Referring again to Figure 1, the ejection switch circuits are extended along the long
31 sides of the elongate lattices of droplet ejectors and the electrode drive conductors
32 from the ejection transistors to the electrodes extend into the lattices of droplet ejectors
33 from either side, such that the connections from the ejection transistors to the
34 electrodes are short (less than the width of the elongate lattice) and of similar length to
35 each other.

36

1 With reference to Figure 4, the electrode drive conductors 240 extend from the driver
2 transistors into the lattice of droplet ejectors along rows, between piezoelectric
3 actuators 320. (Note that Figure 4 is rotated by 90° relative to Figure 1, the width 108
4 is shown for reference). It can be seen from Figure 4 that if the droplet ejector density
5 is to be as high as possible there is very limited space available in a single two
6 dimensional plane for the electrode drive conductors 240, due to the presence of
7 nozzles 344, which are essentially holes through the substrate and also due to a desire
8 to avoid the piezoelectric actuators 320, although in practice a limited amount of
9 overlap with the actuators may be possible.

10
11 Figure 5 is a plan view of rows of 8 actuators being connected to respective drive
12 circuitry 122 on either side of those rows, through electrode drive conductors 240 which
13 extend into the lattice from opposite long sides.

14
15 Figure 6 is a plan view of an embodiment in which rows of 8 actuators are connected
16 to drive circuitry 122 arranged along a single side of the rows. Different regions of
17 electrode drive conductor 240, 240' are arranged in two different CMOS metallisation
18 layers (e.g. M3 and M1). In this plan view the electrode drive conductors in the layer
19 further from the substrate 240 overlie and so partially obscure the conductors closer to
20 the substrate 240'.

21
22 In these arrangement, electrode drive conductors (the conductive connections to
23 actuate the piezoelectric actuators) are relatively short and of consistent length.
24 Accordingly, they actuate the piezoelectric actuators at consistent times. Each
25 electrode drive conductor can be shorter than 1.5 times the width of the droplet ejector
26 zone, or even shorter than the width of the droplet ejectors zone. There is no
27 requirement for electrode drive conductors to extend around the edges of the droplet
28 ejectors zones, which would take up space on the substrate, reducing overall nozzle
29 density and leading to variability in the timing of actuation signals.

30
31 Figure 7 is a plan view of selected components from a portion of the printhead at the
32 left side of Figure 1. A long edge of the substrate comprises bond pads 112 and main
33 CMOS control circuit zone 120 used for timing control, decoding and distributing data
34 etc. A first nozzle zone 114 comprising a lattice of droplet ejectors is located between
35 elongate zones of drive circuitry 122, comprising high voltage transistor circuits
36 surrounded by DTI isolation pockets 310. Strips of CMOS digital control logic 121,
37 being part of the CMOS control circuit zone, extend between strips of drive circuitry.

1
2 The actuator drive waveform conductors 250 are arranged as a two-dimensional grid,
3 extending up each elongate zone of drive circuitry and across droplet ejector zones. A
4 relatively large surface area of these drive waveform conductors is required due to the
5 current which may pass through them in operation and the grid of multiple parallel drive
6 waveform conductors efficiently distributes the waveform signals. It can be seen that
7 some actuator drive waveform conductors 250 extend (widthwise) through the lattice
8 of droplet ejectors parallel to, but in a different metallisation layer to, the electrode drive
9 conductors 240 (connections to three rows only shown for clarity).

10
11 Figures 8 and 9 are plan views of electrical connections comprising both electrode
12 drive conductors and actuator drive waveform conductors 250A, 250B, 250C, 250D
13 extending across a lattice of droplet ejectors. In this example, conductors 250A conduct
14 a first actuator drive waveform for magenta ink ejectors, conductors 250B conduct a
15 second actuator drive waveform for blue ink ejectors and conductors 250C, 250D
16 conduct third and fourth actuator drive waveforms for yellow and black ink ejectors
17 respectively. Each is part of a bus which distributes the respective actuator drive
18 waveform. The actuator drive waveform conductors can be broader than the electrode
19 drive conductors and in this example are located above (i.e. further from the first
20 surface of the substrate) the electrode drive conductors. In Figure 9, only the magenta
21 drive waveform widthwise conductors 250A are shown as connecting to lengthwise
22 conductors running along the drive circuitry 122. As shown in plan view in Figure 10,
23 conductors for other channels/inks extend across the lattice of droplet ejectors, with
24 the conductors for each channel connecting to the drive circuitry on either side of the
25 ejectors for that channel.

26
27 Figure 11 is a cross-section through a printhead substrate according to the invention
28 along a different cross section to Figure 3. In the middle of the image, MEMS
29 metallisation layer 250 is an actuator drive waveform conductor 250 (or one of 250A,
30 250B, 250C, 250D) overlying two electrode drive conductors 240, 240' located in M3
31 and M1 of the CMOS metallisation layers.

32
33 Figure 12 is a cross-section through a printhead substrate according to Figure 3, along
34 a lengthwise cross-section extending between two actuator drive waveform conductors
35 250C, 250D (cross-section through A-A in Figure 8). Underneath the MEMS layers 354,
36 322 and actuator drive waveform conductors, 250C, 250D, there are a plurality of

1 smaller electrode drive conductors 240, 240' located in M3 and M1 of the CMOS
2 metallisation layers 306.

3
4 Figures 13 and 14 correspond to Figure 3 and 11 but for alternative cross-sections
5 showing electrode drive conductors 240 connected to the lower (closer to the
6 substrate) electrode 342 of a droplet ejector and with an actuator drive waveform
7 conductor 250 overlying electrode drive conductors 240, 240'.

8
9 Accordingly, the electrode drive conductors 240 extend only short distances from
10 ejection transistors and each drives only a single droplet ejector. The actuator drive
11 waveform conductors have each to drive one or more whole zones of droplet ejectors.
12 They may require to drive more than 100 or even more than 1000 droplet ejectors.
13 Accordingly, they require to have a significantly larger cross section than the electrode
14 drive conductors. They are accommodated in the MEMS metallisation layers and are
15 broader than the electrode drive conductors in the CMOS metallisation layers. The
16 actuator drive waveform conductors thereby extend in a grid, across zones of droplet
17 ejectors and along CMOS drive circuitry which extend lengthwise between zones of
18 droplet ejectors. Thus, routing of signals, and particularly the actuator drive waveform
19 conductors, around the ends of the zones of droplet ejectors (i.e. along the short sides
20 103 of the substrate) can be minimised or avoided.

21
22 Figure 15 shows a flowchart illustrating a method of manufacturing a printhead module.
23 The method 400 of manufacturing a printhead module comprises forming 410 an
24 integrated circuit (e.g. the CMOS control circuit 224 and the metal interconnect layers
25 306) on the substrate 102. The CMOS circuit is formed by standard CMOS processing
26 methodologies including ion implantation on a p-type or n-type substrate and the
27 interconnect layer is also formed by standard processes such as ion implantation,
28 chemical vapour deposition, physical vapour deposition, etching, chemical-mechanical
29 planarization and/or electroplating.

30
31 Thereafter, the substrate with integrated CMOS circuitry is transferred 420 from a
32 CMOS foundry to a MEMS foundry. Additional layers of material are formed on the
33 substrate to form a MEMS device, including the electrodes 340 and 342, with an
34 intervening piezoelectric body 320 using successive thin film deposition techniques.
35 Thus, the method further comprises forming 430 a plurality of actuators (typically
36 piezoelectric actuators), each to be in electrical communication with the integrated
37 circuit. Each step must avoid damage to the CMOS control circuit. The piezoelectric

1 body is formed of a material such as AlN or ScAlN which may be deposited at a
2 temperature below 450°C by PVD (including low-temperature sputtering). Electrodes
3 are formed of, for example titanium, platinum, aluminium, tungsten or alloys thereof.

4
5 The method further comprises forming 440 a nozzle outlet 344 associated with each
6 actuator. In other words, a plurality of nozzle outlets are formed. Each nozzle outlet is
7 associated with a respective one of the plurality of actuators. Each nozzle outlet
8 extends through the substrate. Typically, each nozzle outlet further extends through
9 one or more further layers on the substrate. The method also comprises forming 450 a
10 print agent manifold for routing print agent therethrough towards the plurality of nozzle
11 outlets. The print agent manifold may be formed before or after the formation of the
12 nozzle outlets. The print agent manifold may be formed before or after the formation of
13 the plurality of actuators. The print agent manifold is a fluid channel defining a fluid
14 communication pathway between a print agent inlet of the printhead module, and the
15 plurality of nozzle outlets. Fluid channels and apertures through the substrate may be
16 formed using etching procedures such as DRIE. A channel defining layer may be
17 formed using DRIE etch and wafer bonding of silicon MEMS substrates. The nozzle
18 defining layer can be formed of metal, silicon MEMS wafer or a plastics material by
19 deposition on or adhesion to the channel defining layer. Each droplet ejector chip is
20 connected to the machine controller via a flexible interconnect 218 containing a limited
21 number of conductors, typically less than 75 or fewer than 50 and potentially fewer than
22 25.

23
24 The material from the which the piezoelectric body is formed cannot be and is not PZT
25 due to the requirement to avoid damaging the CMOS control circuit upon which the
26 piezoelectric actuator, including the piezoelectric body is formed. Accordingly, the
27 piezoelectric actuator has a piezoelectric constant d_{31} which is much lower, usually at
28 least one and potentially two orders of magnitude, less than PZT depending on its
29 precise composition.

30
31 In the embodiments described above, one or more analogue actuator drive waveforms
32 (for example one for each printable fluid type or ink colour) is generated off chip and
33 conducted to the substrate where it is distributed through drive waveform conductors
34 250. In an alternative embodiment, there are instead provided a plurality of voltage rails
35 at different potentials, for example at least three different potentials, and these extend
36 through the substrate instead of drive waveform conductor to the drive circuitry, and
37 the drive circuitry comprises a plurality of transistors per droplet ejector which switch

1 which voltage rail is connect to each of the electrodes of each droplet ejector, over
2 time, during each ejection cycle in which that droplet ejector is selected. For example,
3 there may be a positive voltage, a negative voltage and ground which are switched in
4 turn to provide a droplet ejection waveform.
5
6

1 Claims

2

- 3 1. A printhead for ejecting one or more printable fluids, the printhead comprising
4 a substrate;
5 the substrate defining a plurality of MEMS droplet ejectors for ejecting droplets
6 of the one or more printable fluids and arranged in a lattice, each droplet ejector
7 comprising a flexible diaphragm and a piezoelectric actuator to eject a droplet
8 of a printable fluid through a nozzle by causing movement of the flexible
9 diaphragm, each droplet ejector comprising at least one MEMS metallisation
10 layer;
11 the substrate further defining CMOS control circuitry comprising at least one
12 CMOS metallisation layer;
13 the substrate further comprising one or more of:
14 (i) conductive connections in at least one said metallisation layer,
15 extending from the CMOS control circuitry to each piezoelectric actuator
16 to actuate the piezoelectric actuators; and
17 (ii) conductive connections extending through the lattice in at least one said
18 metallisation layer to conduct actuator drive waveforms.
19
- 20 2. A printhead according to claim 1, wherein the substrate comprises (i)
21 conductive connections in at least one said metallisation layer, extending from
22 the CMOS control circuitry to each piezoelectric actuator to actuate the
23 piezoelectric actuators.
24
- 25 3. A printhead according to claim 2, wherein the length of the conductive
26 connections to actuate the piezoelectric actuators, between the CMOS control
27 circuitry and the piezoelectric actuators within a group of droplet ejectors, is
28 consistent.
29
- 30 4. A printhead according to claim 2 or claim 3, wherein the lattice of MEMS droplet
31 ejectors forms a droplet ejector zone of the substrate, the droplet ejector zone
32 being elongate with a length and a width and with opposite long sides along the
33 length, wherein the conductive connections to actuate the actuators extend into
34 the lattice, from one or two of the opposite long sides of the droplet ejector zone,
35 typically wherein the CMOS control circuitry comprises a plurality of drive
36 transistors at least one of which is connected directly to at least one electrode
37 of the piezoelectric transducer of each MEMS droplet ejector by a said

- 1 conductive connection to actuate the piezoelectric actuators, without
2 intervening transistors, wherein the plurality of drive transistors are arranged in
3 at least one row adjacent the one or two opposite long sides of the droplet
4 ejector zone.
5
- 6 5. A printhead according to claim 4, wherein the conductive connections to
7 actuate the piezoelectric actuators extend into the lattice between rows of
8 MEMS droplet ejectors.
9
- 10 6. A printhead according to any one preceding claim, wherein (ii) conductive
11 connections extend through the lattice in at least one said metallisation layer to
12 conduct actuator drive waveforms, to connect the MEMS droplet ejectors to one
13 or more sources of actuator drive waveforms.
14
- 15 7. A printhead according to claim 6, wherein the conductive connections connect
16 different groups of MEMS droplet ejectors to different ones of a plurality of
17 sources of actuator drive waveforms, to thereby relay different actuator drive
18 waveforms to different groups of MEMS droplet ejectors.
19
- 20 8. A printhead according to claim 6 or claim 7, wherein the droplet ejector zone
21 has a length and a width, and with opposite long sides along the length, wherein
22 the conductive connections to conduct actuator drive waveforms extend into
23 the lattice, from one or two of the opposite long sides of the droplet ejector zone
24
- 25 9. A printhead according to any one preceding claim, wherein each MEMS droplet
26 ejector includes a hole through the substrate for ejection of printable fluid.
27
- 28 10. A printhead according to any one preceding claim, wherein the substrate further
29 comprises conductive connections extending through the lattice in at least one
30 metallisation layer to connect each of the MEMS droplet ejectors to two or more
31 different fixed voltages, wherein the CMOS control circuitry is configured to
32 selectively connect at least one electrode of the piezoelectric actuator of the
33 respective droplet ejector to each of a plurality of the two or more different fixed
34 voltages in turn, responsive to control signals from the CMOS control circuitry.
35

- 1 11. A printhead according to any one preceding claim wherein, in at least a region
2 of the substrate, the one or more MEMS metallisation layers overlie the one or
3 more CMOS metallisation layers.
4
- 5 12. A printhead according to any one preceding claim, comprising a first plurality of
6 conductive connections and a second plurality of conductive connections,
7 wherein the one of the first and second plurality of conductive connections
8 comprises the conductive connections to actuate the piezoelectric actuators
9 and the other of the first and second plurality of conductive connections
10 comprises conductive connections to conduct droplet ejector waveforms or a
11 plurality of different potentials, and wherein at one or more locations within the
12 lattice, at least one first conductive connection and at least one second
13 conductive connection both extend, but in different metallisation layers.
14
- 15 13. A printhead according to any one preceding claim, wherein at one or more
16 locations within the lattice, at least one conductive connection to actuate the
17 piezoelectric actuators and at least one conductive connection to conduct a
18 droplet ejector waveform, extend in parallel between the same adjacent rows
19 of droplet ejectors.
20
- 21 14. A printhead according to any one preceding claims, wherein the lattice
22 comprises at least a first, a second and a third row of MEMS droplet ejectors
23 wherein a plurality of conductive connections extend between droplet ejectors
24 of the first and second row to different respective droplet ejectors along the
25 length of the second row.
26
- 27 15. A printhead according to claim 14, wherein a plurality of conductive connections
28 extend between droplet ejectors of the second and third row to different
29 respective droplet ejectors along the length of the second row.
30
- 31 16. A printhead according to any one preceding claim, wherein the CMOS control
32 circuitry comprises one or more first zones and one or more second zones,
33 wherein the substrate comprises one or more isolation features separating the
34 first and second zones, wherein the one or more first zones comprise
35 transistors which process digital signals and the one or more second zones
36 comprise drive transistors which provide potentials directly to the electrodes of

- 1 piezoelectric actuators, wherein the second zone operates at at least double
2 the maximum potential of the first zone.
- 3
- 4 17. A printhead according to any one claim, wherein the substrate defines a
5 plurality of adjacent droplet ejector zones which are elongate having a length
6 and a width and which are spaced apart orthogonally to their length, wherein
7 between each adjacent droplet ejector zone there is provided at least one
8 CMOS circuitry zone which is also elongate and aligned in the same orientation
9 as the droplet ejectors zones, the CMOS circuitry zone including at least one
10 CMOS metallisation layer, wherein conductive connections extend from the
11 CMOS circuitry into adjacent droplet ejector zones to actuate piezoelectric
12 actuators.
- 13
- 14 18. A printhead according to claim 17, wherein the at least one CMOS circuitry zone
15 comprises both a higher and a lower voltage region, the lower voltage region
16 comprising one or more digital logic gates, the higher voltage region comprising
17 ejection transistors which are directly connected to the piezoelectric
18 transducers of respective droplet ejectors, and wherein the higher and lower
19 voltage regions are separate by an isolation feature in the substrate, typically
20 wherein one or more conductive connections for actuator drive waveforms
21 extend widthwise across one or more droplet ejector zones and connect to a
22 higher voltage region of a CMOS circuitry zone.
- 23
- 24 19. A printhead according to any one preceding claim, comprising a plurality of
25 bond pads in a discrete zone of the substrate.
- 26
- 27 20. Printing apparatus comprising a printhead according to any one preceding
28 claim.
- 29
- 30 21. A method of forming a printhead or printing apparatus according to any one
31 preceding claim, comprising the steps of:
32 forming a lattice of apertures through a substrate, each aperture to at least in
33 part define a fluid chamber of a droplet ejector;
34 forming the CMOS control circuitry, including at least one CMOS metallisation
35 layer, on a first surface of the substrate;

1 forming a MEMS layer, comprising flexible diaphragms, piezoelectric actuators
2 and at least one MEMS metallisation layer, on the first substrate of the
3 substrate, to thereby form the plurality of droplet ejectors;
4 whereby each droplet ejector is conductively connected to the CMOS control
5 circuitry through at least one said metallisation layer.
6