

1 PRINthead ASSEMBLY

2

3 Field of the invention

4

5 The present invention relates to a printhead assembly, a printhead module and a
6 method of manufacturing the printhead module. In particular, the present invention
7 relates to printheads having piezoelectric-actuated printhead nozzles

8

9 Background to the invention

10

11 It is known to manufacture printheads for controllably ejecting print agent from a
12 plurality of printhead nozzles.

13

14 Typically, the printhead assembly is formed from a printhead manifold providing fluid
15 communication between one or more bulk reservoirs for storing the print agent and
16 each of the plurality of printhead nozzles. The plurality of printhead nozzles are
17 mounted to the printhead manifold individually, or in groups. Each printhead nozzle
18 includes an actuator (e.g., a piezoelectric actuator) to control ejection of print agent
19 therefrom.

20

21 To ensure precise and accurate printing using the printhead, it is important that each
22 printhead nozzle is mounted in a predetermined position on the printhead manifold.
23 Thus, it is typically necessary for highly precise manufacturing methods to be used.

24

1 It is in this context that the present invention has been devised.

2

3 Summary of the invention

4

5 In accordance with an aspect of the present invention, there is provided a printhead
6 assembly comprising a plurality of printhead modules, including a first printhead
7 module, a second printhead module and a third printhead module. Each of the plurality
8 of printhead modules comprises: a plurality of printhead nozzles each provided with an
9 actuator for selectively ejecting print agent therefrom; at least one print agent manifold
10 (e.g. a print agent manifold, or a plurality of print agent manifolds) providing a fluid
11 communication pathway between at least one print agent inlet (e.g. a print agent inlet,
12 or a plurality of print agent inlets) and the plurality of printhead nozzles; and control
13 circuitry to control the actuators of the printhead module to eject print agent from the
14 printhead nozzles. The first printhead module is mounted to the third printhead module
15 via the second printhead module.

16

17 Thus, required relative positioning of printhead nozzles to adjacent printhead nozzles
18 can be achieved more precisely, taking account of manufacturing tolerance. By
19 mounting printhead modules to each other, instead of mounting to a common scaffold,
20 any errors in the relative position of adjacent printhead nozzles can be dependent on
21 the manufacturing tolerances of the individual printhead modules, rather than
22 placement errors between independent placement of two separate nozzles.
23 Furthermore, large printhead assemblies can be easily manufactured by providing
24 additional printhead modules connected in series. In contrast, the prior art solution
25 requires that the structural scaffold, to which each printhead module is connected, is
26 manufactured to the required size of the printhead assembly. By mounting the
27 printhead modules to each other, there is no longer a requirement to manufacture a
28 large component with many (sometimes many thousands) of connection ports all
29 precisely located. Although the printhead assembly of the present invention can be
30 mounted to a further component, such as a structural scaffold, it will be understood that
31 any further connections need not be as precise, and/or will not have such a detrimental
32 effect on the output from the printer including the printhead assembly, because the
33 relative location of the printhead nozzles between adjacent printhead modules are
34 already defined.

35

1 It will be understood that a printhead assembly is a component for use in a printer,
2 comprising a plurality of printhead modules which can be connected together during
3 manufacture.

4
5 In some examples, each printhead module is to print only a single print agent from the
6 plurality of printhead nozzles. In other examples, a first subset of the plurality of
7 printhead nozzles are for ejecting a first print agent therefrom and a second subset of
8 the plurality of printhead nozzles are for ejecting a second print agent therefrom. The
9 second subset may be distinct from the first subset. In this way, a single printhead
10 module may be used for printing with a plurality of print agents. Where a plurality of
11 print agents can be printed from the single printhead module, it will be understood that
12 the print agent manifold may provide a fluid communication pathway between a
13 plurality of separate print agent inlets and the respective printhead nozzles associated
14 with each separate print agent among the plurality of printhead nozzles.

15
16 The print agent manifold is substantially any routing for print agent through the
17 printhead module. Typically, the print agent manifold is defined by one or more
18 channels in the printhead module.

19
20 It may be that each printhead nozzle is connected to only one among the plurality of
21 print agent manifolds.

22
23 The printhead nozzle is an opening defined in the printhead module and through which
24 print agent can be controllably ejected by operation of the actuator controlled by the
25 control circuitry. Typically, the printhead nozzles have a cross-sectional extent of less
26 than 1 millimetres, for example less than 0.1 millimetres.

27
28 The actuator may be a piezoelectric actuator. Thus, operation of the piezoelectric
29 actuator for the respective printhead nozzle may be used to controllably eject print
30 agent from the respective printhead nozzle. Use of a piezoelectric actuator allows a
31 simple, precisely controllable printhead assembly to be provided.

32
33 It will be understood that the actuator typically operates to cause displacement of a
34 resiliently deformable membrane defining at least a portion of the printhead nozzle in
35 such a way as to cause ejection of print agent from the printhead nozzle on operation
36 of the actuator.

37

1 By providing the control circuitry as part of the printhead module, again this facilitates
2 a modular nature of construction of the printhead assembly. Furthermore, the
3 complexity of wiring connections in the printhead assembly can be reduced, because
4 separate control wiring to each actuator need only be provided from the control circuitry
5 on each printhead module; the control instructions for any actuators on a printhead
6 module can be provided onto the printhead module via a single wiring connection to
7 the control circuitry on the printhead module. Additionally, where the control circuitry is
8 distributed onto the printhead modules (instead of only located centrally for the
9 printhead assembly) the heat generation from the control circuitry can be distributed
10 across all of the printhead modules, improving heat management for the printhead
11 assembly.

12

13 The control circuitry may comprise an integrated circuit, for example a complementary
14 metal oxide semiconductor, CMOS, circuit. The control circuitry may be integrally
15 formed with the printhead nozzles. In other words, formation of the control circuitry, the
16 printhead nozzles and (optionally) the piezoelectric actuators can be provided at the
17 same time, without requiring assembly of multiple component parts assembled
18 separately. By providing the control circuitry using an integrated circuit, the control
19 circuitry can be provided adjacent the printhead nozzles, thereby ensuring the
20 printhead modules are compact.

21

22 It may be that the control circuitry comprises (a) a digital register. It may be that the
23 control circuitry comprises (b) a nozzle trimming calculation circuit and/or register. It
24 may be that the control circuitry comprises (c) a temperature measurement circuit. It
25 may be that the control circuitry comprises (d) a fluid chamber fill detection circuit.

26

27 The digital register may be a shift register, or a latch register, for example. In operation,
28 it may be that data is stored in or read from a register within the control circuitry. In
29 operation, it may be that temperature is measured using a temperature sensitive
30 component of the temperature measurement circuit. In operation, it may be that the fill
31 level of a fluid chamber is measured.

32

33 It may be that the control circuitry is configured to modify the voltage pulses applied to
34 one or more electrodes of one or more piezoelectric actuators responsive to data
35 stored by the control circuitry or measurements from one or more sensors, which are
36 typically within the printhead module. In operation, it may be that the control circuitry
37 measures the voltage pulses applied to one or more electrodes of one or more

1 piezoelectric actuators responsive to data stored by the control circuitry or
2 measurements from one or more sensors, which are typically within the printhead
3 module.

4
5 Modifying the voltage pulses may comprise shifting them in time. Modifying the voltage
6 pulses may comprise compressing or expanding them. Modifying the voltage pulses
7 may comprise modifying their magnitude. Modifying the voltage pulses may comprise
8 swapping between a plurality of (typically repeating) sequences of received actuator
9 drive pulses with different profiles. The control circuitry is typically configured to modify
10 the voltage pulses applied to one or more electrodes of one or more individual
11 piezoelectric actuators responsive to data relating to that individual piezoelectric
12 actuator stored by the control circuitry or measurements from one or more sensors.

13
14 It may be that the control circuitry comprises an ejection transistor. The ejection
15 transistor is typically in direct electrical communication (without intervening switched
16 semiconductor junction) with an electrode of the piezoelectric actuator. In operation, it
17 may be that the ejection transistor is controlled to cause a potential output from the
18 ejection transistor to be applied directly to an electrode of the piezoelectric actuator.

19
20 The control circuitry may be configured to receive input control signals from outside the
21 printhead module and to output actuator control signals to each of the plurality of
22 actuators to control ejection of print agent from the plurality of printhead nozzles.

23
24 It may be that the printhead module comprises an electrical input for receiving actuator
25 drive pulses. In operation, the printhead module may receive actuator drive pulses.

26
27 The printhead assembly may comprise a controller for controlling the printhead
28 modules of the printhead assembly. The controller may comprise one or more
29 microcontrollers or microprocessors, which may be integrated or distributed, in
30 communication with or comprising a memory storing program code.

31
32 It may be that the controller comprises a pulse generator configured to generate
33 (typically a sequence of) actuator drive pulses. Each printhead module typically
34 comprises an electrical input connected to the controller through which the actuator
35 drive pulses are received. In operation, the printhead assembly may generate actuator
36 drive pulses (e.g. in a controller) and conduct them to the printhead module through an
37 electrical connection. Typically, for one or more printhead modules, the drive pulses

1 are conducted to the respective printhead module via one or more other printhead
2 modules. Typically, the second printhead module is configured to conduct the actuator
3 drive pulses from the first printhead module to the third printhead module.

4
5 The actuator drive pulses are typically analogue signals. The actuator drive pulses
6 typically comprise periodic repeating voltage waveforms.

7
8 It may be that the control circuitry is configured to switchedly connect or disconnect at
9 least one electrode of the or each of a plurality of piezoelectric actuators to the received
10 actuator drive pulses to thereby selectively actuate the piezoelectric actuators. In
11 operation, it may be that the printhead module switchedly connects or disconnects at
12 least one electrode of the or each of a plurality of piezoelectric actuators to the received
13 actuator drive pulses to thereby selectively actuate the piezoelectric actuators.

14
15 It may be that the controller comprises one or more pulse generators which generate
16 a plurality of sequences of actuator drive pulses, and electrical inputs of the printhead
17 module receive the plurality of sequences of actuator drive pulses (generated by the
18 one or more pulse generators) through a plurality of electrical connections to the
19 controller, and the control circuitry is configured to switchedly connect or disconnect at
20 least one electrode of the or each of a plurality of piezoelectric actuators to received
21 actuator drive pulses selected from a plurality of different received sequences of
22 actuator pulses. In operation, it may be that the printhead assembly generates a
23 plurality of different sequences of actuator drive pulses (e.g. in a controller) and
24 conducts them to the printhead module through separate electrical connections, and
25 switchedly connects or disconnects at least one electrode of the or each of a plurality
26 of piezoelectric actuators to one or more received actuator drive pulses received from
27 a variable (and selectable) one of the plurality of different sequences of actuator drive
28 pulses.

29
30 The selection as to which received sequence of actuator pulses at least one electrode
31 of piezoelectric actuator is connected to may be responsive to stored data specific to
32 the respective piezoelectric actuator and/or responsive to measurements of operation
33 of the respective piezoelectric actuator. Accordingly, the control circuitry can typically
34 select whether or not each piezoelectric actuator ejects a droplet at each of a sequence
35 of periodic droplet ejection decision points. By a decision point we refer to a time prior
36 to the start of an actuator drive pulses where it is determined whether or not to
37 communicate that actuator drive pulse to at least one electrode of a specific

1 piezoelectric actuator. In some embodiments the CMOS control circuits can also
2 select, and the method typically comprises selecting, which actuator pulse, from
3 amongst a plurality of actuator pulses, (from the same or different streams of actuator
4 pulses) is applied to at least one electrode of a respective piezoelectric actuator at each
5 said droplet ejection decision point.

6
7 Typically, the actuator drive pulses repeat periodically. It may be that the actuator drive
8 pulses are amplified by the controller. It may be that the actuator drive pulses are not
9 amplified by the printhead module. It may be that the printhead module does not
10 generate actuator drive pulses.

11
12 Typically pulses from the pulse generator are conducted to a plurality of control circuits,
13 which may be part of a plurality of printhead modules. Thus a single pulse generator
14 circuit may drive multiple piezoelectric transducers on the same substrate and/or
15 multiple printhead modules having separate substrates, each having multiple
16 piezoelectric transducers.

17
18 The digital actuation control signals are typically received from a controller. The digital
19 actuation control signals are typically received through a flexible connector. The digital
20 actuation control signals may be received in serial form and converted to parallel
21 control signals using a shift register within the control circuitry.

22
23 It may be that the controller comprises a pulse generator configured to generate
24 actuator drive pulses which are conducted to the printhead module (or a plurality of
25 printhead modules) and digital control signals which are conducted to the printhead
26 module (or a plurality of printhead modules) and the digital control signals are
27 processed in the control circuitry of the printhead module(s) to determine which
28 actuator drive pulses are conducted to at least one electrode of the piezoelectric
29 actuator or piezoelectric actuators of the one or more printhead modules to cause
30 droplet ejection.

31
32 In operation, it may be that the printhead assembly generates actuator drive pulses
33 (e.g. at a controller) and digital control signals, and conducts both the actuator drive
34 pulses and the digital control signals to the control circuitry of the printhead module(s)
35 and the control circuitry processes the digital control signals and, responsive thereto,
36 conducts selected actuator drive pulses to at least one electrode of the piezoelectric

1 actuator or piezoelectric actuator of the one or more printhead modules to cause
2 droplet ejection.

3
4 Thus, typically analogue actuator drive pulse and digital control signals are input by the
5 control circuitry (and typically by the printhead modules). Typically the digital control
6 signals are used to selectively switch the analogue actuator drive pulses to thereby
7 selectively transmit them to the piezoelectric actuators.

8
9 In some embodiments, the control circuitry is configured to switchedly connect one or
10 more of ground and a single fixed non-zero voltage line, or multiple fixed voltage lines
11 of different voltages (one or more of which may be ground) to one or both electrodes
12 of a piezoelectric actuator to cause droplet ejection of print agent. For example, the
13 control circuitry may switch an electrode between a connection to ground and a
14 connection to a fixed voltage or multiple fixed voltage lines of different voltages and
15 back to ground again in order to cause a droplet ejection. Typically, the second
16 printhead module is configured to conduct a said ground and/or a said single fixed non-
17 zero voltage from the first printhead module to the third printhead module.

18
19 Switching an electrode between a connection to ground and a connection to a fixed
20 voltage or between fixed voltage lines may comprise operating a latch.

21
22 It may be that the control circuitry is configured to individually and selectively actuate
23 at least three (or at least four) said piezoelectric actuator elements formed by one or
24 more said layers on the same substrate and defining part of different respective fluid
25 chambers (with different respective droplet ejection outlets, sometimes referred to as
26 printhead nozzles), optionally wherein the said at least three (or at least four) actuator
27 elements are configured for ejecting fluid of different colours or compositions or as
28 redundant droplet ejection outlets.

29
30 It may be that the said at least three (or at least four) piezoelectric actuator elements
31 are located on the substrate (optionally adjacent each other, optionally in a row) and
32 the control circuitry is connected to a flexible printhead cable having one or more
33 electrical signal conductors, wherein the control circuitry is configured to individually
34 and selectively actuate the actuator elements of the at least three (or at least four)
35 piezoelectric actuator elements responsive to actuation commands received through
36 the same signal conductor.

37

1 Thus, due to the integration of the control circuitry which is configured to drive at least
2 three (or at least four) actuator elements, an individual signal conductor may transmit
3 a control signal leading to the actuation of individual actuator elements of the at least
4 three (or at least four) piezoelectric actuator elements. Typically the control signals are
5 digital control signals.

6
7 The at least three (or at least four) piezoelectric actuator elements may comprise or
8 are a group of piezoelectric actuator elements, for example a group of piezoelectric
9 actuator elements which are configured to eject fluid of the same colour or composition
10 (for example have fluid chambers in fluid communication with the same fluid supply),
11 or fluid of different colours or compositions (for example have fluid chambers in fluid
12 communication with separate fluid supplies), or a group of piezoelectric actuator
13 elements which are divided into a plurality of (typically at least three or at least four)
14 sub-groups, wherein the piezoelectric actuator elements in each sub-group are
15 configured to eject fluid of the same colour or composition (for example have fluid
16 chambers in fluid communication with the same fluid supply) and the piezoelectric
17 actuator elements of some or all of the sub-groups are configured to eject fluid of
18 different colours or compositions (for example are in fluid communication with separate
19 fluid supplies). Piezoelectric actuator elements in the same sub-group may be
20 arranged in an array and there may be a plurality of arrays for respective sub-groups.

21
22 It may be that the control circuitry is configured to individually and selectively actuate
23 at least double the number of piezoelectric actuator elements than signal conductors
24 through which the control circuitry receives actuation control signals.

25
26 It may be that the said control circuitry is configured to individually and selectively
27 actuate at least 128 (or at least 256) piezoelectric actuator elements and the control
28 circuitry receives actuation control signals through at most 32 (or at most 16) signal
29 conductors.

30
31 The control circuitry may comprise a serial to parallel conversion circuit configured to
32 convert a digital signal received in serial form through one or more signal conductors
33 into a selection of piezoelectric actuators to be actuated to carry out a droplet ejection
34 simultaneously (i.e. in parallel). The serial to parallel conversion circuit typically
35 comprises one or more shift registers.

36

1 The first printhead module may be configured to be electrically connected to the third
2 printhead module via the second printhead module. It may be that the third printhead
3 module is configured to receive actuation control signals (e.g. digital control signals)
4 via the second printhead module and the first printhead module. Thus, actuator control
5 signals can be input to the first printhead module and relayed by the first printhead
6 module to further printhead modules connected thereto, for example via the further
7 printhead modules connected thereto.

8
9 Each of the printhead modules may receive electric power to power the actuators
10 separately from the actuation control signals. The third printhead module may be
11 configured to receive electrical power via the second printhead module and the first
12 printhead module.

13
14 The print agent manifold of the first printhead module may be different from the print
15 agent manifold of the second printhead module. Thus, the first printhead module may
16 be for a different purpose within the printhead assembly, compared with the second
17 printhead module. It may be that a shape of the print agent manifold of the first
18 printhead module is different to a shape of the print agent manifold of the second
19 printhead module. It may be that one or more internal surface characteristics (such as
20 a surface roughness) of the print agent manifolds differ between the first printhead
21 module and the second printhead module. In other words, the print agent manifold of
22 the first printhead module may be configured for use with a first print agent and the
23 print agent manifold of the second printhead module may be configured for use with a
24 second print agent, different to the first print agent. In some examples, the internal
25 surface of the print agent manifold may be matched to the print agent to be provided
26 thereto.

27
28 The first printhead module may be configured to be operatively coupled to a first print
29 agent to be ejected by a first subset of the plurality of printhead nozzles of the first
30 printhead module, and may be further configured to be operatively coupled to a second
31 print agent to be ejected by a second subset of the plurality of printhead nozzles of the
32 second printhead module. The second print agent may be different from the first print
33 agent. The second subset may be distinct from the first subset.

34
35 Typically, the first printhead module is configured to be operatively coupled to the first
36 print agent via a first print agent inlet of the first printhead module, and to be operatively

1 coupled to the second print agent via a second print agent inlet of the first printhead
2 module.

3

4 Thus, the first printhead module may be configured to connect a plurality of print agents
5 to the plurality of printhead nozzles, to allow ejection of any of the plurality of print
6 agents from the plurality of printhead nozzles. Typically, any given printhead nozzle is
7 configured to selectively eject therefrom only one print agent among the plurality of
8 print agents.

9

10 In one example, the plurality of print agents is greater than two print agents. The
11 plurality of print agents may be less than ten print agents. In some examples, the
12 plurality of print agents is four print agents. Each of the print agents may have a
13 different composition. Where the print agents are inks, each of the plurality of print
14 agents may be a different colour.

15

16 The printhead assembly may further comprise a first module connector for connecting
17 the first printhead module to the second printhead module. The printhead assembly
18 may further comprise a second module connector for connecting the second printhead
19 module to the third printhead module. Thus, there can be intermediate connectors
20 between the printhead modules, but the first printhead module is still nevertheless
21 connected to the third printhead module via the second printhead module.

22

23 In some examples, the first printhead module may be connected directly to the second
24 printhead module, and the second printhead module may be connected directly to the
25 third printhead module. In other words, the first printhead module may be connected to
26 the third printhead module via only the second printhead module between the first
27 printhead module and the third printhead module.

28

29 The print agent manifold of the second printhead module may be arranged to receive
30 the print agent at the print agent inlet from a print agent outlet of the first printhead
31 module. The print agent outlet of the first printhead module may be in fluid
32 communication with the print agent inlet of the second printhead module. Thus, print
33 agent may be provided to the printhead modules via other printhead modules. In this
34 way, it will be understood that a wider extent of a printhead assembly can be provided
35 by simply providing further printhead modules, with no requirement for an increase in
36 the number of print agent sources to the plurality of printhead modules.

37

1 The print agent manifold of the second printhead module may be arranged to receive
2 the print agent at the print agent inlet from a print agent outlet defined in a further print
3 agent manifold, different from the plurality of printhead modules. Thus, the print agent
4 can be supplied to the second printhead module via the further print agent manifold,
5 typically not via any other printhead module in the plurality of printhead modules.

6
7 Each printhead module may comprise at least 10 printhead nozzles. Each printhead
8 module may comprise at least 100 printhead nozzles. Each printhead module may
9 comprise at least 1000 printhead nozzles. Each printhead module may comprise at
10 least 3000 printhead nozzles.

11
12 The plurality of printhead modules may comprise at least 10 printhead modules. The
13 plurality of printhead modules may comprise at least 100 printhead modules.

14
15 The third printhead module may be electrically connected to the first printhead module
16 via the second printhead module. Thus, electrical signals to be received by any of the
17 third printhead module, the second printhead module or the first printhead module, can
18 be supplied to the first printhead module and relayed onwards to the second printhead
19 module, from where they are further relayed to the third printhead module. The control
20 circuitry of the third printhead module may be electrically connected to the first
21 printhead module via the second printhead module. In this way, control signals
22 supplied to the first printhead module can be received by the control circuitry of the
23 third printhead module.

24
25 The plurality of printhead modules may be arranged in a tessellating pattern. Thus, the
26 printhead modules can efficiently fit together without any gaps to ensure a high number
27 of printhead modules can be provided in the space.

28
29 The plurality of printhead modules may together have a plurality of different external
30 shapes, the plurality of different external shapes being less than the number of
31 printhead modules. Thus, there may be a number of repeating external shapes of the
32 plurality of printhead modules. It may be that each of the plurality of different external
33 shapes occurs more than once in the plurality of printhead modules. Thus, a plurality
34 of printhead modules can be produced having each different external shape and used
35 together to form the printhead assembly.

36

1 The plurality of printhead modules may each have a substantially identical external
2 shape. Thus, the external shape of the printhead modules is identical, making it easier
3 to form the printhead assembly from the plurality of printhead modules. It will be
4 understood that even where the plurality of printhead modules have the same external
5 shape, they can have different internal configuration to provide different functionality
6 for one or more of the printhead modules forming a subset among the plurality of
7 printhead modules.

8
9 This in itself is believed to be novel and so, in accordance with another aspect of the
10 present invention, there is provided a first printhead module for connection to a further
11 printhead module having a substantially identical external shape as the first printhead
12 module. The first printhead module comprises: a plurality of printhead nozzles each
13 provided with an actuator for selectively ejecting print agent therefrom; at least one
14 print agent manifold (e.g. a print agent manifold, or a plurality of print agent manifolds)
15 providing a fluid communication pathway between at least one print agent inlet (e.g. a
16 print agent inlet, or a plurality of print agent inlets) and the plurality of printhead nozzles;
17 control circuitry to control the actuators to eject print agent from the printhead nozzles;
18 and a connection portion arranged to facilitate mounting of the first printhead module
19 to the further printhead module.

20
21 Thus, there is provided a printhead module which can be connected with other
22 printhead modules in a modular arrangement to provide a printhead assembly.

23
24 Viewed from another aspect, there is provided a method of manufacturing a printhead
25 module. The method comprises: forming an integrated control circuit in a substrate;
26 forming a plurality of piezoelectric actuators each in electrical communication with the
27 integrated control circuit; forming a plurality of nozzle outlets, each associated with a
28 respective one of the plurality of piezoelectric actuators; and forming at least one print
29 agent manifold (e.g. a print agent manifold, or a plurality of print agent manifolds)
30 defining a fluid communication pathway between at least one print agent inlet (e.g. a
31 print agent inlet, or a plurality of print agent inlets) and the plurality of nozzle outlets.

32
33 Thus, in the context of a printhead assembly having a plurality of piezoelectrically-
34 actuated nozzle outlets, there can be provided a method of manufacturing a modular
35 system of printhead modules. This is enabled by integrally forming the integrated
36 control circuit to connect to and control the plurality of piezoelectric actuators.

1 The plurality of nozzle outlets may extend through the substrate. In some examples,
2 the plurality of nozzle outlets may be defined, at least partially, by the substrate. In
3 some examples, the plurality of nozzle outlets may be defined, at least partially, by one
4 or more further layers, mounted on the substrate. The fluid communication pathway
5 may extend through the substrate.

6
7 Viewed from another aspect, there is provided a method of manufacturing a printhead
8 assembly. The method comprises: manufacturing a first printhead module, a second
9 printhead module and a third printhead module, each manufactured as described
10 hereinbefore; and mounting the first printhead module to the third printhead module via
11 the second printhead module. Thus, the printhead assembly can be formed by
12 mounting printhead modules to each other, instead of mounting the printhead modules
13 solely to a common scaffold structure.

14
15 Viewed from another aspect, there is provided a printer comprising the printhead
16 assembly as described hereinbefore, and one or more sources of print agent in fluid
17 connection with the print agent inlet of the print agent manifold of each printhead
18 module. Thus, the printhead assembly can be used in a printer, as will be understood
19 by the person skilled in the art.

20
21 Viewed from another aspect, there is provided a method of printing comprising:
22 providing the printer; and operating the control circuitry to eject print agent from at least
23 one of the plurality of printhead nozzles of the plurality of printhead modules. Thus, the
24 printhead assembly of the printer can be operated to print using print agent.

25
26 The print agent may be an ink. Alternatively, the print agent may be an additive
27 manufacturing print agent. The print agent will be understood to be substantially any
28 substance capable of being controllably ejected from the plurality of printhead nozzles
29 to be deposited on a surface. The print agent may be liquid. The print agent may be a
30 powder.

31 32 Description of the Drawings

33
34 An example embodiment of the present invention will now be illustrated with reference
35 to the following Figures in which:
36

1 Figure 1 is a schematic diagram showing an arrangement of an actuator,
2 printhead nozzle and control circuitry as disclosed herein;

3 Figure 2 is an illustration of the arrangement shown in Figure 1, including a
4 plurality of printhead nozzles;

5 Figures 3a and 3b are block diagrams of control circuitry for a printhead as
6 disclosed herein;

7 Figures 4a, 4b and 4c are graphical representations of actuator control signals
8 for the circuitry described herein;

9 Figure 5 shows an examples of a printhead module as disclosed herein;

10 Figure 6 shows an arrangement of a plurality of the printhead modules shown
11 in Figure 5; and

12 Figure 7 illustrated a method of manufacture of a printhead module.

13 14 Detailed Description of an Example Embodiment

15
16 Figure 1 is a schematic diagram showing an arrangement of an actuator, printhead
17 nozzle and control circuitry as disclosed herein. With reference to Figure 1, a droplet
18 ejector assembly 100 (functioning as the printhead module) according to the invention
19 comprises a silicon substrate 102 comprising control circuitry 104 on the first surface
20 106 of the silicon substrate 102. The control circuitry 104 is typically an integrated
21 circuit 104 in the form of a CMOS circuit 104. The person skilled in the art will
22 appreciate that a CMOS circuit comprises both doped regions of the substrate and
23 metallisation layers and interconnections formed on the first surface of the substrate.
24 A plurality of layers shown generally as 112 are formed on the first surface 106 of the
25 silicon substrate 102. Layer 112 is the CMOS metallization layer and comprises metal
26 conductive traces and a passivation insulator such as SiO₂, SiN, SiON. The droplet
27 ejector assembly 100 further comprises a piezoelectric actuator 118 comprising a
28 piezoelectric body 120 which in this example is formed of AlN or ScAlN but may be
29 formed of another suitable piezoelectric material which is processable at a temperature
30 of below 450°C. The piezoelectric actuator 118 forms a diaphragm with layers of
31 materials such as silicon, silicon oxide, silicon nitride or derivatives thereof and has a
32 passivation layer 160 (sometimes referred to as a nozzle defining layer 160) which
33 prevents applied electrical potentials from contacting fluid.

34
35 At least one metallisation layer 112 includes interconnects, conducting signals from an
36 external controller via a bond pad 180 to a first portion 105a of the control circuitry 104
37 and from second and third portions 105b, 150c of the control circuitry 104 to the

1 piezoelectric actuator via electrical interconnects 108, in particular to first electrodes
2 140 and second electrodes 142 arranged to apply an electrical potential difference
3 across and thereby actuate the piezoelectric body 120. An opening 120a is defined in
4 the piezoelectric body 120 for passage of the electrical interconnect 108 between the
5 second portion 105b of the control circuitry 104 and the second electrode 142.

6
7 The piezoelectric actuator 118 and accompanying passivation layer 160 defines a wall
8 of a fluid chamber 122 which receives print agent, such as ink (in the case of an inkjet
9 printer) or another printable fluid (for example in the case of an additive manufacturing
10 printer) through a conduit 124 and which is in communication with a printhead nozzle
11 126 for ejecting liquid. The piezoelectric actuator 118 and the nozzle defining layer
12 160 further define a wall of the printhead nozzle 126. The conduit 124 forms at least
13 part of a print agent manifold providing a fluid communication pathway between a print
14 agent inlet (not shown in Figure 1) and the printhead nozzle 126 (as well as further
15 printhead nozzles, not shown in Figure 1). The conduit 124 is defined by the silicon
16 substrate 102, the metallisation layer 112 and the nozzle defining layer 160. A
17 protective front surface 170 provides the external surface of the droplet ejector
18 assembly 100, provided to cover and protect the piezoelectric actuator 118, and
19 abutting against a surface 162 of the nozzle defining layer 160. The protective front
20 surface 170 has apertures which define the nozzles 126. The piezoelectric actuator
21 118, chamber 122 and nozzle 126 together form a droplet ejector shown generally as
22 101.

23
24 Typically, the CMOS control circuit comprises patterned regions of doped silicon and
25 metallisation layers. The number of metallisation layers depends on the complexity of
26 the CMOS control circuit but three layers should suffice for many applications.

27
28 Although only one printhead nozzle 126 and piezoelectric actuator 118 is shown in
29 Figure 1, it will be understood that a plurality of printhead nozzles 126 and
30 corresponding piezoelectric actuators 118 are typically provided. Each piezoelectric
31 actuator 118 is configured to control ejection of print agent from the respective
32 printhead nozzle 126.

33
34 Figure 2 shows an illustration of the arrangement shown in Figure 1, including a
35 plurality of printhead nozzles. With reference to Figure 2 specifically, which shows a
36 printhead module 100a having multiple droplet ejectors 101 (individual piezoelectric
37 actuators, fluid chambers and droplet ejection outlets), flexible cable interconnect 138

1 with a limited number of signal conductors connects an external controller through
2 wires to the printhead module 100a that comprises multiple droplet ejectors shown as
3 101, for ejecting different print agents, for example ink of different colours. The
4 piezoelectric actuators 118, the control circuitry 104 and the printhead nozzles 126,
5 forming multiple droplet ejectors 101, are typically formed from a single CMOS/actuator
6 substrate, though the print agent manifold of each printhead module 100a may be at
7 least partly defined by at least one further component provided in fluid communication
8 with the printhead nozzles 126. In these examples, as well as the main portion of
9 CMOS control circuit 104, the CMOS control circuit includes separate circuit elements
10 104' associated with each droplet ejector, which may for example comprise a latch and
11 an ejector transistor for each piezoelectric actuator.

12

13 Figure 3a is a block diagram of the control circuitry for a printhead assembly. In this
14 example, actuator control is distributed between a machine controller 220 and the
15 control circuitry (e.g., CMOS circuit) 104 within the printhead module 100a. They are
16 connected in part by conductors extending through a single or multiple flexible cable
17 interconnects 138. Multiple actuators 120 are controlled by the application of potentials
18 to their electrodes 140, 142. The machine controller comprises at least a processor
19 200, such as a microprocessor or microcontroller which has memory 202 storing
20 relevant data and program code. A wired or wireless electronic interface 204 receives
21 input data from an external device driver. One skilled in the art will appreciate that the
22 machine controller may be distributed between a number of separate components or
23 functional modules, such as one component which converts an image into a pixelated
24 pattern for printing using a dither matrix, for example, and a separate component which
25 converts the pixelated pattern into a print pattern for the different nozzles.

26

27 The machine controller may comprise at least one waveform generator and a voltage
28 amplifier 208 which provides a continuous pattern of actuator control pulses (shown in
29 Figure 4) to the printhead through one or more drive signal conductors 210. A ground
30 conductor 212 also extends from the machine controller to the droplet ejector assembly
31 100. (Ground connections within printhead not shown for clarity). The processor 200
32 generates digital control signals 214 typically as a serial bus, and also transmits clock
33 signals 216 to the printhead which serve to synchronise printing with movements of the
34 printhead. The connector also provides voltage levels associated with the operational
35 voltage of CMOS control electronics.

36

1 Within the printhead module 100a, contact pads 136 are connected to the conductors
2 of the flexible connector and signals are routed through patterned metallised layer 112
3 to the CMOS control circuit 104 and from the CMOS control circuit to the electrodes
4 140, 142 which actuate individual piezoelectric bodies 120 within respective
5 piezoelectric actuators. The control circuit 104 on substrate 102 comprises ejection
6 switch circuit 220, including ejection transistors having outputs which are in direct
7 electrical connection with the electrodes 140, 142 (i.e. without a further intervening
8 switching semiconductor junction). The ejection switch circuit switches the actuator
9 control pulse signals and if one of the electrodes remains connected to ground, the
10 ejection switch circuit may be as simple as single transistor per actuator, or a single
11 transistor per electrode to switch the signal applied to that electrode. The ejection
12 switch circuit may be distributed around the substrate with a portion (e.g. a transistor
13 or transistor and latch) proximate each droplet ejector.

14

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

19

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

32

33 Figure 3b is a further block diagram for control circuitry for a printhead assembly. The
34 control circuitry is substantially similar to that described in relation to Figure 3a, but the
35 electrical signals (e.g. the actuator control pulses via drive signal conductors 210, the
36 digital control signals 214 and the clock signals 216) are transferred to the printhead
37 modules 100a, 100b, 100c together. In other words, the electrical signals 210, 214, 216

1 are transferred to the third printhead module 100c via the first printhead module 100a
2 and the second printhead module 100b. In this way, it will be understood that electrical
3 connection between the machine controller 220 and the plurality of printhead modules
4 100a, 100b, 100c can be provided even where the machine controller 220 is only
5 directly electrically connected to the first printhead module 100a.

6
7 Each printhead module 100a, 100b, 100c includes control circuitry 104 and a plurality
8 of (e.g. at least two) actuators 120, and the electrical signals can provide actuation of
9 any combination of one or more of the actuators 120 on any of the plurality of printhead
10 modules 100a, 100b, 100c via the control circuitry 104 on each printhead module 100a,
11 100b, 100c. Each of the electrical signals 210, 214, 216 is electrically connected to the
12 control circuitry 104 of each of the printhead modules 100a, 100b, 100c.

13
14 The electrical signals typically comprise address information indicative of the particular
15 printhead module 100a, 100b, 100c, as well as the particular actuator 120 on the given
16 printhead module 100a, 100b, 100c, to be operated to cause ejection of print agent
17 from the printhead nozzle associated with the operated actuator 120.

18
19 Figures 4(a), 4(b) and 4(c) show three possible drive waveforms generated by
20 waveform generator or voltage amplification 206 in alternative embodiments. The x
21 axis is time (in milliseconds) and the y axis is potential per μm thickness of actuator.
22 As the piezoelectric bodies are made of a non-ferroelectric material in this example the
23 pulses may be applied in either direction. In Figure 4(a) the signals have a default
24 voltage of 0 and in each pulse are switch to a positive potential and back to zero after
25 a predetermined period of time. In Figure 4(b) the signals have a default voltage of 0
26 and are switched first to a positive potential (to cause the piezoelectric actuator to
27 deform in one direction) and then to a negative potential (to cause the piezoelectric
28 actuator to deform in the opposite direction) before returning to zero. In Figure 4(c) the
29 signals have a default voltage of 200V and are switched to a voltage of -200V (causing
30 the electric fields in the piezoelectric body to reverse in direction) before returning to
31 200V.

32
33 During operation, the processor 200 receives printing data, such as bitmaps, in digital
34 form through interface 204 and processes this data by known means to send a
35 sequence of printing instructions through serial connection 216 to each printhead
36 module. These printing instructions may be as detailed as instructions for each
37 printhead module as to whether and when to eject a droplet during printing cycles. In

1 one embodiment, the waveform generator generates repeating voltage pulses suitable
2 for application to the electrodes of individual piezoelectric actuators. These are
3 periodic with a time spacing which determines the time between droplet ejection events
4 on the printhead. Alternatively, the voltage amplification, 208, may provide and
5 maintain a single voltage level of multiple voltage levels to the printhead assembly.
6 The ejection transistors within the printhead module will switch these voltages
7 according to the CMOS control circuit.

8
9 As the waveform generator or generators are not located on the printhead and is used
10 to drive numerous piezoelectric actuators, it or they can generate a significant amount
11 of heat without causing problems. There are not substantial substrate space limitations
12 so it or they may be relatively complex circuits adapted to carefully control the shape
13 of the waveform, with selected, and optionally variable, slew rates, and the power
14 amplifier may be selected to produce the desired voltage up to the maximum possible
15 current requirement in the event that all actuators which may be actuated
16 simultaneously be actuated together.

17
18 The control circuit 224 on an individual printhead substrate receives the printing
19 instructions through serial connection 216 and processes these (for example
20 converting from serial to parallel instructions). With reference to the clock signals 214,
21 it is determined whether each individual piezoelectric actuator should be actuated to
22 eject a droplet during each printing cycle and this data is loaded into latches 222. At
23 an appropriate time during each printing cycle, the latched data is passed to the
24 ejection switch circuit which thereby either switch the received printing waveform to the
25 electrodes of the respective actuator element, causing it to carry out a droplet ejection
26 cycle, or to not do so in which case both electrodes of the respective actuator element
27 remain connected to ground and the droplet ejector does not carry out a droplet
28 ejection cycle.

29
30 Sensors 232, 234, 236 are monitored during printing. The precise timing of switching
31 the received printing waveform to the electrodes of the respective actuator element can
32 be varied responsive to a measure of temperature using a temperature sensitive
33 CMOS element.

34
35 Each nozzle may have slightly different ejection characteristic behaviour (drop volume,
36 velocity) based on variance in wafer manufacturing (on a single wafer - or between
37 wafer lots), due to printhead assembly, due to actuation lifetime. This data can be

1 used to alter the drive waveform for specific nozzles by the CMOS control circuit - for
2 example - changing the actuation pulse duration or switching to a different level - or to
3 switch certain nozzles to different drive waveforms.

4
5 The viscosity and surface tension of some inks is highly sensitive to temperature - this
6 ultimately changes the droplet ejection characteristics. Certain print patterns will result
7 in certain nozzles firing continuously whereas others fire sporadically. This will result
8 in a variable heat pattern. The monitored temperature can be used by the control circuit
9 to modify waveforms and/or feedback control information to the controller for
10 appropriate action such as reducing print speed etc.

11
12 The shift registers move the droplet fire pattern information through to the latch
13 registers. Thus, the shift registers interface with the serial connection, and move all
14 print data to the latch registers in a given print cycle. The latch registers interface with
15 the ejection registers to initiate a print command.

16
17 Figure 5 shows a printhead module 300 as disclosed herein, and to be connected to a
18 plurality of other printhead modules (as shown in Figure 6). The printhead module 300
19 includes a print agent inlet 310, in the form of a plurality of print agent inlets 310. Print
20 agent enters the printhead module 300 through the print agent inlet 310, and can be
21 internally routed in one or more print agent manifolds (not shown in Figure 5), to a
22 plurality of printhead nozzles as described hereinbefore. In this example, the print
23 agent inlet 310 is on a lateral side of the printhead module 300. The printhead module
24 300 further includes a print agent outlet 320, through which print agent not expelled
25 from the printhead module 300 through the printhead nozzles, can be relayed to further
26 printhead modules connected to thereto. In other words, the print agent outlet 320 is
27 configured to align with the print agent inlet 310 of a further printhead module.

28
29 The printhead nozzles are provided in a print region 340, from which print agent is to
30 be controllably ejected in operation of the printhead module 300.

31
32 The or each of the print agent manifolds may be specific to the particular printhead
33 module 300. The surface properties of the print agent manifolds may be configured to
34 match the print agent to be supplied thereto.

35
36 Control and/or power signals are provided to the printhead module 300 via a flexible
37 interconnect 330.

Figure 6 shows an arrangement 400 of a plurality of printhead modules 300, connected together in an assembled arrangement. In the present example, there are four rows of printhead modules 300, each row including five printhead modules 300, though it will be understood that other configurations are possible.

Although only five printhead modules 300 are labelled in Figure 6 for clarity, it will be understood that Figure 6 includes a total of 20 printhead modules 300.

From Figure 6, it will be seen that the plurality of printhead modules 300 tessellate perfectly, meaning that there are no gaps therebetween, thereby providing a particularly space-efficient arrangement of printhead modules 300. However, in other examples, there may be spaces between some portions of the printhead modules 300.

The arrangement 400 includes a first row 410, a second row 420, a third row 430 and a fourth row 440. The second row 420 is offset from the first row 410, such that the print regions 340 of the printhead modules 300 in the first row 410 laterally only partially overlap the print regions 340 of the printhead modules 300 in the second row 420. The third row 430 and the fourth row 440 are offset in a similar way to the first row 410 and the second row 420, such that the print regions 340 of the third row 430 are substantially laterally matched with the print regions 340 of the first row 410, and the print regions 340 of the fourth row 440 are substantially laterally matched with the print regions 340 of the second row 420. Thus, in some examples, the fourth row 440 can provide redundancy for the second row 420, and the third row 430 can provide redundancy for the first row 410. In other examples, different print agents can be provided to the printhead nozzles of the corresponding printhead modules in the overlapping rows.

The arrangement 400 of printhead modules shown in Figure 6 can be used to provide redundancy in the printhead modules 300.

It will be understood that the shape of the printhead module 300 is not limited to that shown, and could be in any suitable shape to be connected to further printhead modules 300.

Figure 7 shows a flowchart illustrating a method of manufacturing a printhead module. The method 500 of manufacturing a printhead module comprises forming 510 an

1 integrated circuit (e.g. the CMOS control circuit 104, 134 and the metal interconnect
2 layer 112) on the substrate 102. The CMOS circuit is formed by standard CMOS
3 processing methodologies including ion implantation on a p-type or n-type substrate
4 and the interconnect later is also formed by standard processes such as ion
5 implantation, chemical vapour deposition, physical vapour deposition, etching,
6 chemical-mechanical planarization and/or electroplating.

7
8 Additional layers of material are formed on the substrate, including the electrodes 140
9 and 142, with an intervening piezoelectric body using successive thin film deposition
10 techniques. Thus, the method 500 further comprises forming 520 a plurality of
11 actuators (typically piezoelectric actuators), each to be in electrical communication with
12 the integrated circuit. Each step must avoid damage to the CMOS control circuit. The
13 piezoelectric body is formed of a material such as AlN or ScAlN which may be
14 deposited at a temperature below 450°C by PVD (including low-temperature
15 sputtering). Electrodes are formed of, for example titanium, platinum, aluminium,
16 tungsten or alloys thereof.

17
18 The method 500 further comprises forming 530 a nozzle outlet associated with each
19 actuator. In other words, a plurality of nozzle outlets are formed. Each nozzle outlet is
20 associated with a respective one of the plurality of actuators. Each nozzle outlet
21 extends through the substrate. Typically, each nozzle outlet further extends through
22 one or more further layers on the substrate. The method 500 also comprises forming
23 540 a print agent manifold for routing print agent therethrough towards the plurality of
24 nozzle outlets. The print agent manifold may be formed before or after the formation of
25 the nozzle outlets. The print agent manifold may be formed before or after the formation
26 of the plurality of actuators. The print agent manifold is a fluid channel defining a fluid
27 communication pathway between a print agent inlet of the printhead module, and the
28 plurality of nozzle outlets. Fluid channels and apertures through the substrate may be
29 formed using etching procedures such as DRIE. Channel defining layer 128 may be
30 formed using DRIE etch and wafer bonding of silicon MEMS substrates. The nozzle
31 defining layer can be formed of metal, silicon MEMS wafer or a plastics material by
32 deposition on or adhesion to the channel defining later. Each droplet ejector chip is
33 connected to the machine controller via a flexible interconnect. In contrast to prior art
34 devices according to Figure 1, the number of discrete conductors in the flexible
35 interconnect is limited, for example 4 to 16 conductors.

36

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

7
8 It will be understood that the printhead modules may have alternative configurations
9 from those described herein.

10
11 The flexible interconnect may be mounted to an edge of a printhead assembly and
12 used to drive several or many individual printhead modules, for example printhead
13 modules for different colours of ink (or other materials in the case of an additive printer)
14 or droplet ejectors for different colours of ink (or other materials) may all be formed in
15 a single continuous substrate in an individual printhead module.

16
17 In an alternative embodiment, instead of the machine controller including a waveform
18 generator and the waveform being conducted to the printhead modules and the CMOS
19 control circuit thereon, the CMOS control circuit actuates the piezoelectric actuators,
20 causing droplet ejection, by switching the voltage applied to one or more of the
21 electrodes of each piezoelectric actuator, for example between ground and a fixed
22 voltage, or between multiple fixed voltage levels, one or more of which may be ground.
23 In this case, the flexible connector 138 contains one or more electrical conductors
24 carrying a fixed voltage from the machine controller to the printhead module.

25
26 In summary, there is provided a printhead assembly comprising: a plurality of printhead
27 modules (100a), including a first printhead module, a second printhead module and a
28 third printhead module. Each of the plurality of printhead modules (100a) comprises: a
29 plurality of printhead nozzles (126) each provided with an actuator (118) for selectively
30 ejecting print agent therefrom; at least one print agent manifold (122, 124) providing a
31 fluid communication pathway between at least one print agent inlet and the plurality of
32 printhead nozzles (126); and control circuitry (104) to control the actuators (118) of the
33 printhead module (100a) to eject print agent from the printhead nozzles (126). The first
34 printhead module is mounted to the third printhead module via the second printhead
35 module.

36
37

1 Claims

2

- 3 1. A printhead assembly comprising:
4 a plurality of printhead modules, including a first printhead module, a second
5 printhead module and a third printhead module, each of the plurality of printhead
6 modules comprising:
7 a plurality of printhead nozzles each provided with an actuator for
8 selectively ejecting print agent therefrom;
9 at least one print agent manifold providing a fluid communication
10 pathway between at least one print agent inlet and the plurality of printhead
11 nozzles; and
12 control circuitry to control the actuators of the printhead module to eject
13 print agent from the printhead nozzles,
14 wherein the first printhead module is mounted to the third printhead module via
15 the second printhead module.
16
- 17 2. The printhead assembly of claim 1, wherein the actuator is a piezoelectric
18 actuator.
19
- 20 3. The printhead assembly of claim 1 or claim 2, wherein the control circuitry
21 comprises a CMOS circuit.
22
- 23 4. The printhead assembly of any preceding claim, wherein the at least one print
24 agent manifold of the first printhead module is different from the at least one
25 print agent manifold of the second printhead module.
26
- 27 5. The printhead assembly of any preceding claim, wherein the first printhead
28 module is configured to be operatively coupled to a first print agent to be ejected
29 by a first subset of the plurality of printhead nozzles of the first printhead
30 module, and further operatively coupled to a second print agent to be ejected
31 by a second subset of the plurality of printhead nozzles of the first printhead
32 module, the second print agent different from the first print agent and the
33 second subset distinct from the first subset.
34
- 35 6. The printhead assembly of any preceding claim, further comprising a first
36 module connector for connecting the first printhead module to the second
37 printhead module and a second module connector for connecting the second
38 printhead module to the third printhead module.

- 1
2 7. The printhead assembly of any preceding claim, wherein the at least one print
3 agent manifold of the second printhead module is arranged to receive the print
4 agent at the at least one print agent inlet from at least one print agent outlet of
5 the first printhead module in fluid communication with the at least one print
6 agent inlet of the second printhead module, or
7 wherein the at least one print agent manifold of the second printhead
8 module is arranged to receive the print agent at the at least one print agent inlet
9 from a print agent outlet defined in a further print agent manifold, different from
10 the plurality of printhead modules.
- 11
12 8. The printhead assembly of any preceding claim, wherein the plurality of
13 printhead modules are arranged in a tessellating pattern, and/or wherein the
14 plurality of printhead modules each have a substantially identical external
15 shape.
- 16
17 9. The printhead assembly of any preceding claim, wherein each printhead
18 module comprises at least 100 printhead nozzles.
- 19
20 10. The printhead assembly of any preceding claim, wherein the third printhead
21 module is electrically connected to the first printhead module via the second
22 printhead module, such that control signals supplied to the first printhead
23 module can be received by the control circuitry of the third printhead module.
- 24
25 11. A first printhead module for connection to a further printhead module having a
26 substantially identical external shape as the first printhead module, the first
27 printhead module comprising:
28 a plurality of printhead nozzles each provided with an actuator for
29 selectively ejecting print agent therefrom;
30 at least one print agent manifold providing a fluid communication
31 pathway between at least one print agent inlet and the plurality of printhead
32 nozzles;
33 control circuitry to control the actuators to eject print agent from the
34 printhead nozzles; and
35 a connection portion arranged to facilitate mounting of the first printhead
36 module to the further printhead module.
- 37
38 12. A method of manufacturing a printhead module comprising:

- 1 forming an integrated control circuit in a substrate;
2 forming a plurality of piezoelectric actuators each in electrical communication
3 with the integrated control circuit;
4 forming a plurality of nozzle outlets, each associated with a respective one of
5 the plurality of piezoelectric actuators; and
6 forming at least one print agent manifold defining a fluid communication
7 pathway between at least one print agent inlet and the plurality of nozzle outlets.
8
- 9 13. A method of manufacturing a printhead assembly, the method comprising:
10 manufacturing a first printhead module, a second printhead module and
11 a third printhead module, each according to the method of claim 12; and
12 mounting the first printhead module to the third printhead module via the
13 second printhead module.
14
- 15 14. A printer comprising the printhead assembly of any of claims 1 to 10, and one
16 or more sources of print agent in fluid connection with the at least one print
17 agent inlet of the at least one print agent manifold of each printhead module.
18
- 19 15. A method of printing comprising:
20 providing the printer of claim 14; and
21 operating the control circuitry to eject print agent from at least one of the
22 plurality of printhead nozzles of the plurality of printhead modules.
23
24