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(54) Abstract Title
**Manufacture of piezoelectric print head**

(57) In the method a composition of piezoelectric ceramic paste, plasticiser and a material which becomes electrically conductive after sintering, which composition is capable of being fired to form a highly conductive but mechanically compatible material, is extruded through an appropriately formed and dimensioned extrusion die to produce an extrudate in the form of an elongate strip having internally a multiplicity of tubular cavities extending the length of the extrudate, the walls of which cavities are the piezoelectric ceramic paste/plasticiser/conductor composition which, when fired, forms a conductive electrode layer on the surface of those walls.

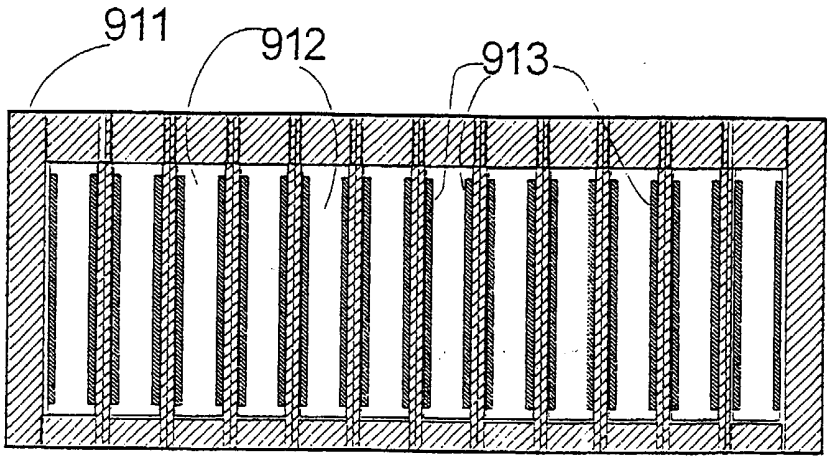


Fig. 1

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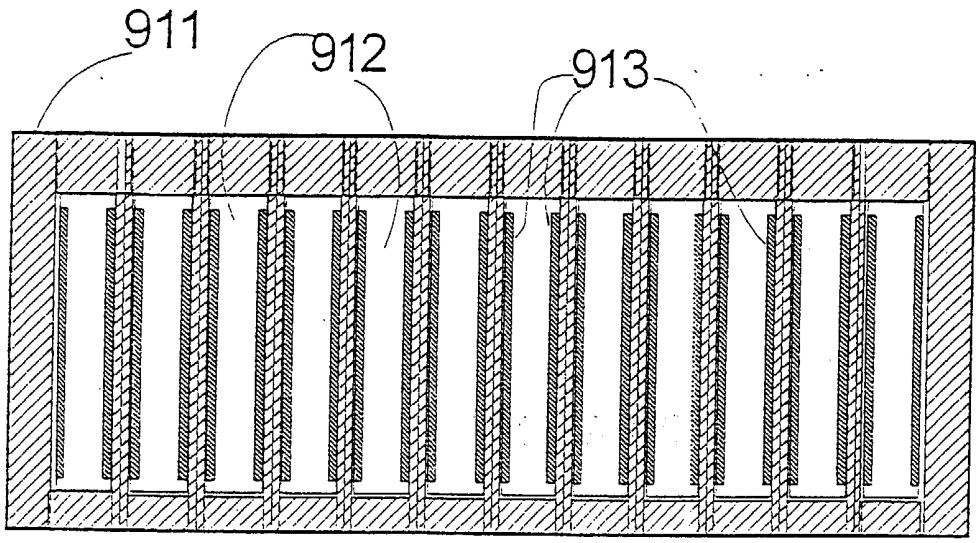


Fig. 1

# Manufacture of Piezoelectric Print Head

The present invention relates to manufacture of a piezoelectric actuator, like that which is used in ink-jet printing.

In this type of device there is formed a block of piezoelectric material having a planar array of a large number of very fine, very close parallel chambers therewithin into which ink can be fed at one end and from which ink can be pumped out of extremely small apertures at the other end. The chambers are provided with opposed electrodes on either side, and when these are activated the piezoelectric material deforms, reducing the volume of the relevant chambers, and so driving ink out through the apertures.

These piezoelectric print-heads are presently manufactures by a laborious, multistage process, as follows. First, a suitable thick sheet of piezo-ceramic has milled into one major face a series of elongate parallel slots, leaving between the slots thin walls upon which are deposited electrodes. A top-plate of piezoceramic is then bonded on top of the milled face of the sheet, covering the slots and making bonded contact with the tops of each of the slot-walls, thus forming by means of this fabrication a series of parallel approximately rectangular tubes within the body of the composite structure. Finally, end plates are bonded onto the edges of the laminate perpendicular to the direction of the slots, to close off the tubes so formed, and into one these end-plates are bored precision holes, often using a laser beam, to form extremely fine nozzles.

In use, ink is allowed to enter the chamber *via* additional holes into the slotted chambers, and when a drop of ink is to be ejected the electrodes on the slot side walls are driven electrically in such a way as to deform the slot walls and reduce the volume of the associated rectangular tubular chamber, this reduction in volume causing the virtually incompressible ink to be ejected through the nozzle (some other arrangement is provided to prevent the ink being ejected through the filler holes). In

practice the procedure is more complex than this brief description makes it seem; it involves, for example, carefully-timed waves being launched into the ink so as to cause the required ink flow.

This type of structure is capable of producing very fine resolution ink-jet print heads, and is already highly developed. However, its composite multi-process construction makes it a high-cost item, and the non-availability of large sheets of appropriate ceramic material prevents efficient mass manufacture of multiple devices. The process involves: the grinding to flatness of the piezoceramic base plate and lid-plate (currently necessary to ensure good mechanical alignment and bonding); the milling operation to produce a series of slots in the base plate; the metal deposition process to provide electrodes on the side walls of the cavities, and any ancillary intermediate cleaning operations between milling and metal deposition; and the alignment and bonding of the top plate to the milled and slotted base plate and any ancillary intermediate cleaning operations between metal deposition and bonding.

It is a further purpose of this invention to describe an alternative, and much simpler and cheaper, manufacturing method for such devices, and for other similar devices.

The invention proposes that an ink-jet print-head style device be made by a simple multi-layer extrusion process of a type similar to that pioneered by Pearce *et al* at the IRC for Materials, University of Birmingham, to make co-extruded hollow PZT tubes and multilayer PZT bender structures complete with integral conductive electrode layers. Using an appropriately formed and dimensioned extrusion die together with a multilayered composition of piezoelectric ceramic paste and plasticiser, some layers of which have been well mixed with a conduction-producing material (such as silver oxide) to make a highly conductive but mechanically compatible material after firing, there is provided an extrudate in the form of an arbitrarily long strip - its length is determined only by the quantity of material to be extruded - having internally a multiplicity of tubular cavities,

extending the length of the extrudate, the walls of which are the piezoelectric ceramic paste/plasticiser/conductor composition which, when fired, forms a conductive electrode layer on the surface of those walls.

The invention provides a method for making a channelled piezoelectric device like that required for a piezoelectric ink-jet print head, in which method a composition of piezoelectric ceramic paste, plasticiser and a material which becomes electrically conductive after sintering, which composition is capable of being fired to form a highly conductive but mechanically compatible material, is extruded through an appropriately formed and dimensioned extrusion die to produce an extrudate in the form of an elongate strip having internally a multiplicity of tubular cavities extending the length of the extrudate, the walls of which cavities are the piezoelectric ceramic paste/plasticiser/conductor composition which, when fired, forms a conductive electrode layer on the surface of those walls.

The invention provides a method for making a channelled piezoelectric device like that required for a piezoelectric ink-jet print head. An instance of a device other than a print head is a micro-pump of the sort used either for metered drug administration or for controlling sample flow in chromatographs.

The invention provides a piezo-device-manufacturing method in which there is employed a composition of piezoelectric ceramic paste, plasticiser and a material that makes the sintered composite ceramic electrically-conductive. This composition is in use extruded, and is then capable of being fired to form a highly conductive but mechanically compatible material.

Suitable piezoelectric materials for making the ceramic include those Morgan-Matroc substances mentioned hereinbefore - Morgan-Matroc PZT-4D, PZT-5A or PZT-5H. They may conveniently be plasticised using PVA, and adding silver oxide to them makes them conductive after sintering.

The method of the invention requires the composition to be extruded through an appropriately formed and dimensioned extrusion die to produce an extrudate. A

co-extrusion die is most likely to be useful for this purpose. Here, two material entry points are provided into the die, which ultimately are extruded from the one and the same aperture or set of apertures (in the case of a multi-nozzle ink-jet pump die). Material is forced into the input apertures - plasticized active PZT paste into a first aperture, and a similar material but with the addition of the well-mixed-in conductivity-providing agent (eg silver oxide) into the other. Within the die, the main body of the extrudate is formed from material from the first aperture; however, the die is so arranged that a thin layer of (potentially conductive) material from the second aperture is deposited to the side wall positions of each of the slots or rectangular holes that appear in the extrudate, the die-internal pressures being such that the co-extruded materials, from the two input apertures are mutually in contact at the output aperture(s) to form a single continuous but laminated body of extrudate thereat.

In this method the composition is extruded to produce an extrudate in the form of an elongate strip having internally a multiplicity of tubular cavities extending the length of the extrudate. Most commonly the tubular cavities will preferably be rectangular in cross-section (the section is determined by the die apertures), but other convenient and easily-attainable section shapes are circular or elliptical (such sections are very difficult to produce by machining).

There is no practical limit to the length of continuous extrudate possible with this process, as material may be fed continuously into the input apertures. However, a practical limit of some tens of feet (several metres) for the sintering furnace dictates cutting the extrudate (extruded onto a carrier which provides support thereafter until completion of sintering) into corresponding lengths (or less). In a direct replacement for the present manufacturing process (by machining) the apertures may be rectangular.

The extrusion method produces an elongate strip having internally a multiplicity of cavities the walls of which are the piezoelectric ceramic paste/ plasticiser/conductor composition which, when fired, forms a conductive electrode

layer on the surface of those walls.

The co-extruded post-sintered conductive layers will generally be made as thinly as careful process control allows, but in any case in the 10-250micrometre range. The layers on either side of the active PZT material forming the walls between the rectangular cavities, become conductive after sintering, and so provide the means by which in the device's use those walls can be electrically driven (and thereby deformed).

It will be seen that by means of the invention's simple, continuous, extrusion process there can be produced in one single operation, and in a manner that eliminates a great deal of complex and expensive processing (and so is at a considerably reduced cost), the types of structures needed for the variety of ink-jet print head previously described.

Whereas in the presently-used methods the whole assembly is required to have precise dimensional accuracy to allow registration of the separate components, in the method of construction of the invention there is far less requirement for absolute precision, as ultimately the only part that requires significant precision alignment are the ink-jet nozzles (which may be bored in an end plate in a similar manner as at present, and thus each can be positioned relative to the other nozzles with adequate precision by that process alone).

It will also be appreciated that the novel form of construction proposed here may also be used as the basis for a wide range of fluid pumping devices other than ink-jet print heads, to which the disclosed technique is in no way limited.

An embodiment of the invention is now described, though by way of illustration only, with reference to the accompanying diagrammatic Drawing in which Fig. 1 shows a section through a simple piezoelectric ink-jet print head device according to the invention (it is to be imagined that a long strip of channelled body has been extruded, and has then been cut transversely into usable lengths; Fig. 1 shows one of the faces produced by such a transverse cut).

The print-head has a piezoelectric body portion (911) within which are a number of channels (as 912) defined by wall portions, and on the channel-facing surfaces of these are conductive layers (as 913). In operation, ink is fed into each channel 911 *via* ports (not shown: they would be in a blanking plate sealed over the cut face), and when a drive signal is applied to the electrodes 913 lining any particular channel 912 the walls flex, pumping some of the ink therein out through very fine apertures (not shown: they would be in another blanking plate sealing off the other end - also not shown - of the cut length).

Claims

1. A method for making a channelled piezoelectric device, in which method a composition of piezoelectric ceramic paste, plasticiser and a material which becomes electrically conductive after sintering, which composition is capable of being fired to form a highly conductive but mechanically compatible material, is extruded through an appropriately formed and dimensioned extrusion die to produce an extrudate in the form of an elongate strip having internally a multiplicity of tubular cavities extending the length of the extrudate, the walls of which cavities are the piezoelectric ceramic paste/plasticiser/conductor composition which, when fired, forms a conductive electrode layer on the surface of those walls.

2. A method as claimed in Claim 1 in which the channelled piezoelectric device is suitable as a piezoelectric ink-jet print head.

3. A method as claimed in either of Claims 1 or 2, in which the piezoelectric material is a PZT substance, the plasticiser is PVA, and the potentially conductive material is silver oxide.

4. A method as claimed in any of Claims 1 to 3, in which the composition is extruded through an appropriately formed and dimensioned co-extrusion die, having two material entry points, or input apertures, and one and the same exit aperture or set of exit apertures, and the die is so arranged internally that a thin layer of (potentially conductive) material from the second input aperture is deposited to the side wall positions of each of the slots that appear in the extrudate, the die-internal pressures being such that the co-extruded materials, from the two input apertures are mutually in contact at the output aperture(s) to form a single continuous but

laminated body of extrudate thereat.

5. A method as claimed in any of Claims 1 to 4, in which the tubular cavities are of rectangular-section.

6. A method as claimed in any of Claims 1 to 5 and substantially as described hereinbefore.

7. A fluid pumping device prepared by a process as claimed in any of Claims 1 to 6.

**Application No:** GB 0124972.1 **Examiner:** Peter Easterfield
**Claims searched:** 1 to 7 **Date of search:** 21 November 2001

# Patents Act 1977
# Search Report under Section 17

## Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.S): B6F (FLQ)

Int Cl (Ed.7): B41J 2/16

Other: Online: WPI, EPODOC, JAPIO

## Documents considered to be relevant:

| Category | Identity of document and relevant passage | Relevant to claims |
|---|---|---|
| A | JP 050050606 A (BROTHER) see abstract | |
| A | JP 040353463 A (BROTHER) see abstract | |

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