MULTILAYER PIEZOELECTRIC ACTUATOR WITH BENDING DEFORMATION AND METHOD FOR ITS MANUFACTURE

FIELD OF THE INVENTION

The present invention relates to piezoelectric actuators and methods for manufacturing such actuators.

BACKGROUND ART

In general, multilayer actuators and bimorph actuators are two important types of prior art piezoelectric ceramic actuators.

The conventional multilayer piezoelectric ceramic actuator has a laminated body that is formed by alternately laminating a plurality of piezoelectric ceramic layers and a plurality of internal electrode layers, each electrode layer being interposed between two ceramic layers. Each group of even and odd numbered electrodes, each of which is sandwiched between a couple of piezoelectric ceramic layers, is connected to a respective external electrode. For the multilayer piezoelectric ceramic actuator thus prepared, voltage applied across the external electrode pair is applied respectively to each piezoelectric ceramic layer. As a result, the piezoelectric ceramic layers sandwiched between internal electrodes deform in the thickness direction thereof in accordance with the voltage applied. The deformations induced in the respective ceramic layers accumulate in the laminating direction, and so the conventional multilayer actuator has a voltage controllable displacement in the laminating direction.

Such multilayer piezoelectric actuators have several advantages: quick response, large generative force, and high electromechanical coupling. Many applications, such as a printer heads and X-Y stages have been attempted using the multilayer actuators.

However, for this type of actuator, a higher displacement/voltage sensitivity can only be achieved by greatly increasing the number of the piezoelectric layers and decreasing the thickness of each layer, and hence may result in higher cost, lower reliability and yield, and larger overall dimensions.

The bimorph type piezoelectric actuator is composed of two ceramic plates bonded together. The bimorph causes a bending deformation and hence displacement in the transverse direction because it consists of two piezoelectric plates which are bonded together and each plate produces extension or contraction under an electric field. Compared with the multilayer stack structure, the bimorph structure has a lower resonance frequency and smaller generative force, but is a simple structure with low cost and high displacement/voltage sensitivity. This type of actuator has been applied in video head tracking devices, swing CCD mechanism etc.

In known fabrication processes for bimorph actuators, the two ceramic plates are bonded using cohesive coatings, such as resin. However, this method is not efficient to realize a multilayer structure having low driving voltage, miniaturization and hybridization.

The bend of the prior art bimorph actuator occurs in the direction in which the two plates are bonded and the drive voltage is applied. For a bimorph actuator having one-end clamped and having specific length and material parameters, the resonance frequency is proportional to the dimension in the bending direction, but the displacement/voltage sensitivity of the tip of the cantilever beam is inversely proportional to the square of the said dimension value. Increasing the dimension in the thickness or the lamination direction increases the resonance frequency but is

unfavourable to the displacement/voltage sensitivity, and *vice verse*. Thus, for the bimorph actuator, since the field is applied in the same direction in which the bend occurs, the improvement of the resonance frequency and the displacement/voltage sensibility is restrained.

In some specific applications, such as the magnetic head tracking mechanism in hard disk drives, high displacement/voltage sensitivity, as well as high resonance frequency, is critical to the servo control system. The applicability of these two types of actuators for such applications is restrained due to the low resonance frequency of the bimorph structure and the low displacement/voltage sensitivity of the multilayer structure. It is disclosed in US Patent 5,189,578 that a multilayer piezoelectric actuator is built in the distal end portion of the head supporting arm of the hard disk drive so as to precisely position the head. However, in order to achieve sufficient displacement, the large number of the piezoelectric layers required can greatly increase the cost, and/or the required voltage is too high to be applied within a hard disk drive. Moreover, the large mass and moment of inertia to be driven by the actuator and the additional mechanical structure unfavourably affect the feasibility of the entire dynamic mechanism. To date, piezoelectric actuators have not been widely accepted for head tracking applications in hard disk drives.

The so-called tape casting method is a preferable method for preparing multilayer piezoelectric ceramic actuators, as disclosed, for example, in US Patent Nos. 5,507,898 and 5,245,734. Generally, in the tape casting process, a slurry of piezoelectric powders, organic solvent and binder is cast and molded into a green sheet on a tape using a doctor blade. Then a plurality of green sheets, each coated with an electrode, are laminated.

After thermal compression bonding, the laminated body is sintered at high temperature. To make each group of even and odd electrodes connected to a respective external electrode, preferably, two methods are commonly adopted, being either:

(1) glass insulating coatings provided on the edges of the internal electrodes arranged in the laminating direction and alternatively disposed on the opposing side surfaces of the laminated body; or

(2) an interdigital internal electrode structure.

Screen printing technology, also known in the art as "thick film" technology, is another method for preparing solid-state sensors and actuators. In thick-film printing the substrate, screen and paste come together at the screen printer. Generally, a rubber squeegee blade traverses the top surface of the screen at a controlled speed, the pressure causing thixotropic paste to flow through the pattern on the screen and hence onto the substrate. Snap-off and squeegee pressure affect the thickness of the wet print to some extent. A paste of piezoelectric powders and an organic vehicle is forced through an aperture in a stencil screen and printed onto a substrate. After thick film printing, the substract is allowed to stand in order to remove mesh marks, dried and then co-fired with a specific profile. Electrode and piezoelectric layers are deposited alternatively to form a sandwiched structure, and the printed films are sintered at a high temperature to form the so-called "thick-film" device.

Recent references about single piezoelectric "thick-films" include B. Morten et al, Hybrid Circuit 28 (1992), 25-28, Sensors and Actuators A31 (1992), 153-158, Microelectronics International 38 (1995), 5-11, IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control 43 (1996), 73-77; H.D. Chen et al, Journal of

Applied Physics 77 (1995) 3349-3353; J.F. Fernandez et al., 30 (1995) 5359-5404. It is known that "thick-film" technology can also be used to fabricate multilayer piezoelectric actuators, as described by H. Moilanen et al in Sensors and Actuators A, Vol. 37-38 (1993) 106-111, Vol. 41-42 (1994) 421-425, Vol. 43 (1994) 357-365, and Microelectronics International 37 (1995) 28-30.

It is an object of the present invention to overcome or ameliorate one or more of the disadvantages of the prior art, or at least to provide a useful alternative.

SUMMARY OF THE INVENTION

According to a first aspect of the invention there is provided a multilayer piezoelectric device including a plurality of piezoelectric layers alternately laminated with a plurality of electrode layers, wherein each electrode layer includes a separate pair of first and second electrodes, the first electrode being disposed adjacent a first side of said device and the second electrode being disposed adjacent a second side of said device such that selective application of voltage to said electrodes causes extension of said first side and contraction of said second side, thereby bending said device.

Preferably, the first and second sides of the laminated body are much larger in length than the width and thickness of the laminated body. The width of the laminated body is preferably much larger than the thickness of each piezoelectric layer or the thickness of the laminate body. The first and second sides lie in the longitudinal direction for the cantilever structure application. The longitudinal direction is perpendicular to the lamination direction. The term "width" stands for the dimension in the transverse direction, in which the bending occurs, and is perpendicular to the

longitudinal direction. The term "thickness" refers to the lamination direction which is the direction in which the field is applied.

Preferably, a polarization vector in each layer of the multilayer body is parallel with the lamination direction. For a first portion of the multimorph body, the driving electric field in each layer is parallel with the polarization vector in the same layer, and for a second portion of the multilayer body, they are anti-parallel. Thus, synchronised extension and contraction in the longitudinal direction can be caused in the two halves of the multimorph, respectively, so that bending displacement can be generated.

According to a second aspect of the invention, there is provided a process for producing a multilayer piezoelectric device including the steps of:

a) alternately laminating a plurality of piezoelectric layers with a plurality of electrode layers to form a laminate body, whereby each electrode layer includes a separate pair of first and second electrodes, the first electrode being disposed adjacent a first side of said device and the second electrode being disposed adjacent a second side of said device; and

b) co-firing said laminate body.

Preferably the layers are formed using screen-printing, i.e., the process uses the so-called "thick film" technique. The layers are preferably formed on a substrate by multiple screen-printing, and then the laminate body is released from the substrate and fired.

Further preferably an organic film is deposited on a substrate, and the multilayer body is printed on the organic film of the substrate. Then the organic film is burnt off at

a moderate temperature so that the multilayer body can be released from the substrate and fired at higher temperatures without the substrate.

To improve the quality of the laminate body, preferably the multilayer green body is compressed by applying mechanic pressure before the final firing.

The preferred embodiments of this invention provide a piezoelectric actuator having the merits of high displacement/voltage sensitivity by virtue of the multilayer structure, high resonance frequency by virtue of the increased dimension in which bending occurs and low cost.

The preferred processes for producing the preferred embodiments are compatible with known industrial manufacture processes so as to keep high yield and productivity, and low cost.

BRIEF DESCRIPTION OF THE DRAWINGS

Various preferred features and embodiments of the present invention will now be described, by way of non-limiting example, with reference to the accompanying drawings, in which:

Fig. 1 shows a schematic illustration for the assembly of the multiple electrode and dielectric layers in accordance with one embodiment of the present invention;

Fig. 2 shows an embodiment of the electrode morphology of two adjacent electrode layers;

Fig. 3 and 4 show the structure and working principle for an embodiment of an actuator according to the invention;

Fig. 5 shows a flow chart for an embodiment of the thick film preparation process;

Fig. 6 shows a view of one embodiment of a stencil which may be used to deposit the piezoelectric film and the internal electrode to prepare the structure shown in Fig. 3;

Fig. 7 shows a flow-chart for an embodiment of the tape casting preparation process for the actuators;

Fig. 8 shows another embodiment of an actuator according to the present invention composed of trapezoid-shaped layers.

DESCRIPTION OF THE EMBODIMENTS

Preferred embodiments of the invention will now be described with reference to the accompanying drawings.

Fig. 1 shows an exploded view of a multilayer piezoelectric device including a plurality of piezoelectric layers 2 alternately laminated with a plurality of electrode layers 1. As shown in figure 2, each electrode layer includes a separate pair of first and second electrodes, one pair being shown by reference numerals 1a and 2a, another pair being shown by reference numerals 1b and 2b. The first electrode 1a or 1b of each pair is disposed adjacent a first side 30 of the device and the second electrode 2a, 2b is disposed adjacent a second side 31 of said device. The electrodes are placed such that selective application of voltage to the electrodes causes extension of said first side 30 and contraction of said second side 31, thereby bending said device. In practice, selective application of voltage can result in bending extension or contraction of either side, thereby bending said device in either direction. In this embodiment, the ceramic layer 2 is formed of a piezoelectric ceramic consisting mainly of lead titanate zirconate, $Pb(Zr,Ti)O_3$, (so-called PZT), and the internal electrode 1 is formed of a palladium-silver (Pd-Ag) mixture. Excess PbO is added to the PZT to promote the sinter process and to

compensate for Pb loss due to volatilization at high firing temperature. Each piezoelectric layer 2 (also known as PZT layer) is rectangular shaped in cross section, having first and second sides 30 and 31 which are opposite and parallel to each other and which are elongate, in other words having a dimension much longer than the width 32 of the device as shown in Fig. 3. The directions corresponding to the "longitudinal direction", the "lamination or thickness direction" and the "width direction" are shown in figure 1 as arrows 40, 41 and 42 respectively. Each PZT layer in this embodiment has a thickness of about 60-70 μm, width of 3.5 mm, and a length of 11 mm. Each electrode 1, which is split into two symmetric parts, has a thickness of about 3-5 μm. The pattern of the electrodes in each electrode layer alternates between a first pattern 1a or 2a and a second pattern 1b or 2b. The electrodes having the first pattern each include a finger 3a or 4a extending longitudinally from the device, both fingers 3a and 4a being disposed adjacent a longitudinal axis of symmetry of the device, said axis of symmetry lying in plane 33. The electrodes 1b or 2b having the second pattern each include a finger 3b or 4b extending longitudinally from the device. Both fingers being disposed adjacent the first and second sides 30 and 31 respectively.

The edges of the fingers, designated as 5a and 6a in the odd electrodes and 5b and 6b in the even electrodes are exposed at the side surface of the laminate body, which is designated as 7 in Fig. 3, and connected to the external electrodes 8. The fingers 3a and 4a of the odd electrode are spaced by much smaller distance d_1 in the widthwise direction than the distance d_2 between fingers 3b and 4b in the even electrode. Each of the exposed edges of the four fingers, 5a, 6a, 5b and 6b, do not overlap in the thickness direction. Sufficient space in the widthwise direction between the exposed edges of each

of the four types of electrode fingers facilitates the electrical connection of the electrode group composed of 1a, 2a, 1b and 2b in each layer to the separate external current collector 8a, 8b, 8c and 8d, respectively. In other words, the fingers 5a, 6a, 5b and 6b align to collectively form four electrode groups such that each group can be connected respectively to an external electrode.

Thus, each PZT layer is sandwiched between two pairs of electrodes, 1a versus 1b, and 2a versus 2b. The two electrodes of each pair are opposed in the thickness direction. The multilayer actuator has first and second portions 34 and 35 lying on either side of plane of symmetry 33 shown in Fig. 1. The first portion 34 includes the two electrode groups of 1a and 1b, and the corresponding half of the PZT multilayer body. The second portion 35 includes the two electrode groups of 2a and 2b, and the other half of the PZT multilayer body.

The poling electric field can be applied to each half of each piezoelectric ceramic layer through the external electrodes 8a, 8b, 8c and 8d. Preferably, there are two poling modes for the actuator, as shown in Fig. 3 and Fig. 4, respectively. In Figs. 3 and 4, the polarization vectors of the two parts of each PZT layer are parallel or antiparallel with a transverse axis of the actuator lying in the lamination direction.

The driving field (or voltage) is so applied on each half of PZT layer that the electric field is parallel to the polarization vector in each PZT layer in one portion 34 or 35 of the multilayer body, but anti-parallel to the polarization vector in each PZT layer in the other portion 34 or 35, as shown in Figs. 3 and 4. Consequently, each PZT layer in one portion of the multilayer body extends synchronistically in the longitudinal direction, and each PZT layer in another portion of the multilayer body contracts in the

longitudinal direction. Thus, a transverse bending deformation is realized in the widthwise direction. With the end of the actuator clamped to form a cantilever beam, a displacement of the free end is produced.

In one preferred embodiment, the thick film screen print process, as shown in Fig. 5, is used to fabricate such multilayer actuators. Fine PZT powder with a particle size preferably below 1 μm is mixed with 5 weight percent (%) lead oxide powder in a ball mill, and then a commercial organic vehicle from Electro-Science Laboratory, Inc. (Product #400 vehicle) is added in a weight ratio of ceramic powder: organic vehicle = 76:24, and the mixture is milled for 24 hours in a ball mill to improve its homogeneity. The use of the organic vehicle gives rise to a PZT-based piezoelectric paste having a suitable viscosity, rheology, and thixotropy for the following printing process.

Commercial photoresist AZ1518 from Hoechst is deposited on alumina substrate by spin-coating. After drying at 150°C for 30 minutes, the photoresist coating is fired at 350°C for 30 minutes.

For efficiency, preferably two screen printers are adopted to print the PZT and the Pd-Ag film, each through their respective stencil screen. Fig. 6(a) shows a preferred stencil pattern for printing the Pd-Ag electrode with alignment mark a_n, and 6(b) shows a preferred stencil pattern for PZT layer with alignment b_n. Preferably, only one screen stencil, as shown in Fig. 6(a), is used to print both the first electrode patterns 36 and the second electrode pattern 37 so as to improve the alignment accuracy.

Each electrode element has two extended fingers at the end. The space between the two fingers 3a, 4a, 3b or 3b is same for all the elements arranged on one line, but different from that of the elements arranged on the adjacent lines. Each PZT pattern is

rectangular-shaped. The sequence of the multiple printing and alignment operation are described as below.

Initially, a first electrode layer is printed on a fired photoresist layer on an alumina substrate, and a first PZT layer is printed on the dried first electrode layer with marks b_1 to b_6 aligned with a_3 to a_8, respectively, which deposited on the substrate during the printing of the first layer. Nine of the twelve electrode elements are covered by the nine PZT elements. When printing the second electrode layers, the screen marks a_1 to a_6 should be aligned with the marks b_1 to b_6, respectively, which were deposited on the substrate during the printing of the first PZT layer. The second PZT layer is printed with its marks just overlapping that of the first PZT layer to keep that the PZT layer precisely overlapped. The third electrode is printed with marks of a_3 to a_8 aligned with marks of b_1 to b_6 of the PZT layer. The deposition of the PZT and Pd-Ag electrode layers may be repeated alternately layer by layer until the desired number of layers is achieved. Thus, for each individual actuator element, all the PZT layers and electrode layers are directly above each other, and all the odd numbered electrodes or all the even numbered electrodes have either the first or second electrode pattern, M or N, respectively provided the odd electrode is different from the even electrode. The electrodes with small spaced fingers M and the electrodes with large spaced fingers N are interposed to each multilayer element alternately. So a plurality of multimorph green bodies as shown in Fig. 3 and Fig. 4 are constructed.

The photoresist coated alumina substrate with attached multilayer green bodies are first fired at 650°C to burn off all the organic compositions including the photoresist

layer so that the multilayer green bodies can be released from the alumina substrate. Then all the individual multilayer elements are co-fired at 1130°C.

The end of the multilayer body is cut transversely and polished to expose all the internal electrode edges. Conductive silver paste is used to connect all the even electrode edges and all the odd electrode edges in each portion 34 or 35 of the multilayer bodies. So a total of four external electrodes are formed, and four conductive leads, 8a, 8b, 8c and 8d, are bonded onto the conductive silver paste to form the external electrodes.

A modified embodiment of the above described is that the PZT pattern in the screen stencil is much larger than the individual electrode elements so that the deposited PZT layer can cover a plurality of the electrodes. Thus each printed ceramic multilayer element contains a plurality of the individual electrode multilayers. A plurality of individual actuators are obtained from one ceramic multilayer unit after separation cutting.

A further embodiment of the above described process is that mechanical pressure is applied to the green multilayer body before or after it is released from the substrate to improve its density and lamination. More preferably, the multilayer body is loaded into a flexible container, preferably a soft plastic bag with good tenacity. The soft plastic bag is evacuated using a vacuum pump and then the bag is hermetically packaged. The package is completely immersed in a liquid medium in a chamber of an isostatic pressure machine. The isostatic pressure in the liquid is built up to preferably 3000 kg/cm^2 and is held for 10 minutes.

In another preferable embodiment, the ceramic layers of the multimorph are formed using a tape casting process, as shown in Fig. 7. First, an appropriate piezoelectric ceramic powder consisting of PZT and 5 weight percent (%) lead oxide powder, is mixed with a small amount of an organic binder, and dispersed into an organic solvent by ball milling. The resulting mixture is defoamed under a reduced pressure to obtain a slurry. Then the slurry is molded by a tape casting process while using a doctor blade and the molded product is naturally dried for 24 hours to obtain a green sheet with a thickness of about 100 μm.

Subsequently, Pd-Ag electrode paste is printed to one surface of the above described PZT green sheet. The electrode screen stencil with two kinds of electrode patterns, designated as M and N respectively in Fig. 6(a), is used to print both the odd and even numbered electrode layers. Using only one screen stencil and printer is favourable to achieve high alignment accuracy. In another preferable embodiment, two screen stencils, each having a plurality of one of split electrode patterns M and N, are used to print the electrode layer onto one surface of the PZT green sheet.

An appropriate number of sheets with electrode coating are so aligned and laminated that each element of the PZT layer contacts electrode pattern M and N on its two sides, respectively. The laminated body thus obtained is heated under the application of a pressure of 200 kg/cm^2 and sintered at 1130°C.

Finally, the laminated bodies are cut into a plurality of individual elements so as to expose the edges of the extended electrode fingers for connection to the external electrodes. The external electrodes are prepared in the same way as that described for the thick film process.

With one of the longitudinally spaced ends of the actuator clamped to form a cantilever structure, the transverse displacement of the free end is over 1.3 μm under a drive voltage of 12V, and the corresponding resonance frequency is above 20 kHz. Such an actuator shows a much higher displacement/voltage sensitivity than the conventional multilayer actuator, and much higher resonance frequency than a normal bimorph actuator with the same displacement/voltage sensitivity. Additionally, the PZT layer shows good dielectric properties with a room temperature dielectric constant of about 1100, and dielectric loss at 1 kHz of about 0.6%.

The success of combining the high displacement/voltage sensitivity and the high resonance frequency makes the piezoelectric actuator presented in this invention capable of being applied for the magnetic head tracking mechanism in hard disk drive system.

It should be noted that the displacement/voltage sensitivity is not determined by the number of the laminated layers in the thickness direction. A large number of the laminated layers is not a prerequisite to produce large displacement. So only a few of piezoelectric layers are sufficient to form an actuator according to the invention instead of tens or even hundreds of layers required by the conventional multilayer actuator to realize large displacement. Thus the manufacture cost can be greatly reduced.

The parallelepiped shaped actuators of Figs. 1 to 4 are only disclosed as an example to explain the structural characteristics, working principle and the preparation process. Any other shape may also be adopted. Another preferable multimorph actuator, as shown in Fig. 8 is composed of a plurality of trapezoid-shaped piezoelectric layers 21, and a plurality of split trapezoid-shaped electrode 22 with extended fingers 23, giving an actuator having a hexahedron shape.

THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:-

1. A multilayer piezoelectric device including a plurality of piezoelectric layers alternately laminated with a plurality of electrode layers, wherein each electrode layer includes a separate pair of first and second electrodes, the first electrode being disposed adjacent a first side of said device and the second electrode being disposed adjacent a second side of said device such that selective application of voltage to said electrodes causes extension of said first side and contraction of said second side, thereby bending said device.

2. A multilayer piezoelectric device according to claim 1 wherein said first and second sides are elongate, having a dimension much larger than a width of said device.

3. A multilayer piezoelectric device according to claim 1 or 2 wherein said first and second sides are opposite each other.

4. A multilayer piezoelectric device according to claim 1 wherein each piezoelectric layer is substantially rectangular in cross section, having two opposite parallel elongate sides disposed in said first and second sides of said device respectively.

5. A multilayer piezoelectric device according to claim 4 wherein the device is a rectangular parallelepiped.

6. A multilayer piezoelectric device according to any one of claims 1 to 3 wherein each piezoelectric layer is substantially trapezoidal, having two opposite, non-parallel sides disposed on said first and second sides of said device respectively.

7. A multilayer piezoelectric device according to claim 6 wherein the device is a hexahedron.

8. A multilayer piezoelectric device according to any one of the preceding claims wherein a polarisation vector in each piezoelectric layer is parallel or anti-parallel with a transverse axis of said device lying in the lamination direction.

9. A multilayer piezoelectric device according to claim 8 wherein a driving electric field can be applied to a first portion of said device adjacent said first side such that said electric field is substantially parallel with said polarisation vector, thereby causing extension of said first side.

10. A multilayer piezoelectric device according to claim 8 or 9 wherein a driving electric field can be applied to a second portion of said device adjacent said second side such that said electric field is substantially anti-parallel with said polarisation vector, thereby causing contraction of said second side.

11. A multilayer piezoelectric device according to any one of the preceding claims wherein the pattern of each electrode layer alternates between a first pattern and a second pattern.

12. A multilayer piezoelectric device according to claim 11 wherein the electrodes having said first pattern each include a finger extending longitudinally from said device, both fingers of each electrode pair being disposed adjacent a longitudinal axis of symmetry of said device.

13. A multilayer piezoelectric device according to claim 11 or 12 wherein the electrodes having said second pattern each include a finger extending longitudinally from said device, both fingers of each electrode pair being disposed adjacent said first and second sides respectively.

14. A multilayer piezoelectric device according to claim 13 wherein said fingers align to collectively form four electrode groups, such that each group can be connected respectively to an external electrode.

15. A process for producing a multilayer piezoelectric device including the steps of:

a) alternately laminating a plurality of piezoelectric layers with a plurality of electrode layers to form a laminate body, whereby each electrode layer includes a separate pair of first and second electrodes, the first electrode being disposed adjacent a first side of said device and the second electrode being disposed adjacent a second side of said device; and

b) co-firing said laminate body.

16. A process for producing a multilayer piezoelectric device according to claim 15, wherein said step of alternately laminating a plurality of piezoelectric layers with a plurality of electrode layers involves screen-printing piezoelectric ceramic layers and electrode films alternately onto a substrate, then releasing a multilayer green body from the substrate.

17. A process for producing a multilayer piezoelectric device according to claim 16 further including preparing an organic film on said substrate prior to said laminating, then burning off said organic layer at a moderate temperature so as to release said multilayer green body from said substrate.

18. A process according to claim 16 or 17 in which the multilayer green body is laminated by applying mechanical pressure on the body before or after the body is released from the substrate.

19. A process according to claim 18 in which said pressure is isostatic.

20. A process according to any one of claims 15 to 19 in which a plurality of separate multilayer elements, each with only one set of electrode and piezoelectric layers, are disposed on a substrate in a multiple printing cycle.

21. A process according to any one of claims 15 to 19 in which each deposited piezoelectric layer covers a plurality of sets of electrode layers, such that a plurality of individual piezoelectric multilayer devices are obtained after separation cutting.

22. A process for producing a multilayer piezoelectric device including the steps of:

a) moulding piezoelectric ceramic slurry into sheets;

b) printing an electrode layer onto the sheets, whereby each electrode layer includes a separate pair of first and second electrodes, the first electrode being disposed adjacent a first side of said device and the second electrode being disposed adjacent a second side of said device;

c) forming a laminate body by laminating a plurality of sheets by applying mechanical pressure such that at least a part of two adjacent ceramic sheets has an electrode layer sandwiched therebetween;

d) co-firing said laminate body.

23. A process for producing a multilayer piezoelectric device according to claim 22 in which each electrode layer printed in step b) includes a plurality of separate pairs of first and second electrodes, and further including the step of:

e) cutting the laminate body into individual devices.

24. A process for producing a multilayer piezoelectric device according to claim 22 or 23, wherein said piezoelectric slurry is moulded into sheets by a doctor blade.

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25. A process for producing a multilayer piezoelectric device according to any one of claims 15 to 24, wherein multiple copies of electrodes having a first pattern, and electrodes having a second pattern are printed using a single screen stencil having both patterns.

26. A process for producing a multilayer piezoelectric device according to claim 25 wherein the positions on said screen stencil of at least some of the electrodes having said first and second patterns can be exchanged with each other by translational movement.

27. A process for producing a multilayer piezoelectric device according to claim 25 or 26 wherein said screen stencil reciprocates with translational movement after each printing of an electrode layer so as to alternate between said first and said second electrode patterns.

28. A multilayer piezoelectric device substantially as herein described with reference to any one of the embodiments shown in the accompanying drawings.

29. A process for producing a multilayer piezoelectric device substantially as herein described with reference to any one of the embodiments shown in the accompanying drawings.