(19) LE GOUVERNEMENT
DU GRAND-DUCHÉ DE LUXEMBOURG
Ministère de l'Économie

(11) N° de publication : **LU100594**

(12) # BREVET D'INVENTION **B1**

(21) N° de dépôt: LU100594

(51) Int. Cl.:
H01L 41/047, H01L 41/08, H01L 41/083, H01L 41/29

(22) Date de dépôt: 22/12/2017

(30) Priorité:

(43) Date de mise à disposition du public: 28/06/2019

(47) Date de délivrance: 28/06/2019

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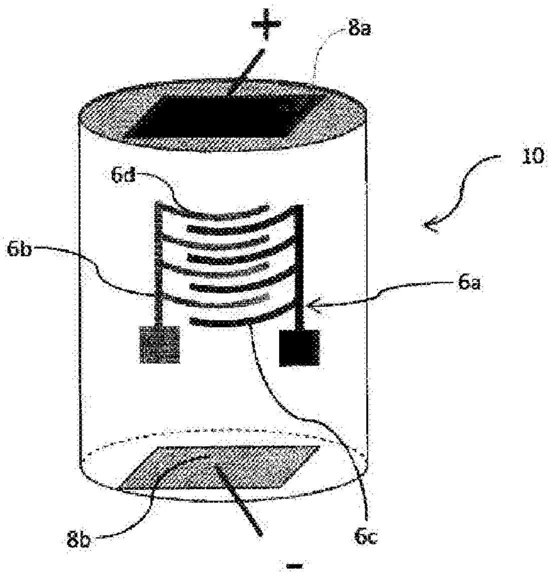
(54) **PIEZOELECTRIC DEVICE WITH A SENSOR AND METHOD FOR MEASURING THE BEHAVIOUR OF SAID PEIZOELECTRIC DEVICE.**

(57) The first object of the invention is directed to a piezoelectric device (10) shaped as a tridimensional object with at least two surfaces, wherein said piezoelectric device (10) comprises a first set of two or more electrodes (8a, 8b). Said piezoelectric device (10) is remarkable in that at least one of the surfaces which is free of electrodes from said first set of two or more electrodes (8a, 8b) is covered with at least a second set of electrodes. The second object of the invention is directed to a method for measuring the behaviour of a piezoelectric device.



PIEZOELECTRIC DEVICE WITH A SENSOR AND METHOD FOR MEASURING THE BEHAVIOUR OF SAID PIEZOELECTRIC DEVICE

Description

Technical field

[0001] The invention is directed to the field of the piezoelectric material. More particularly, the invention is directed to the field of the measurement of the deformation of the piezoelectric actuator.

Background art

[0002] In the field of piezoelectric device, it is known to couple a sensor to an actuator by bonding or gluing, thus requiring different material to manufacture a sensor. This also increases the number of steps for the fabrication of such material, such as the step for activating the bonding. For instance, US patent application published US 2007/0165333 A1 describes a piezoelectric sensor bonded through a non-conductive adhesive to a piezoelectric actuator to determine the pressure and/or the temperature.

[0003] One example of piezoelectric device (used in the filtration of information) is surface acoustic wave (SAW) device. A SAW device is a piezoelectric device in which an input transducer and output transducer are on the same outer surface of the device. The input transducer (that can be considered as an actuator) and the output transducer (that can be considered as a sensor) are generally interdigitated electrodes and must be on the same surface in order to transform the electrical energy into a mechanical energy in the form of SAWs. Therefore, no galvanic isolation is achieved. Moreover, the interdigitated electrodes are deposited by precise deposition technique, such as lithography or photolithography, which forces the user to functionalize the piezoelectric device on a same and single surface.

[0004] US patent application published US 2009/0009193 A1 describes a moisture-sensitive element which consists in a sensing layer formed on a interdigital capacitor which is formed on a printed circuit board (PCB). This moisture-sensitive element works by applying an electric field between the two electrodes composing the interdigital capacitor. Thus, if moisture (water) enters the electric field, the total dielectric constant of the interdigital capacitor will increase and this variation can be detected by a LCR meter that is then placed between the electrodes of the interdigital capacitor.

[0005] The system known in the art are limited on the fact that either the actuator and the sensor must be on a similar surface (in the case of SAW device, as explained above) or that the sensor are embedded inside a device (in the case of the moisture-sensitive element). The adhesion of further material between the actuator and the sensor is also required.

Summary of invention

Technical Problem

[0006] The invention has for technical problem to alleviate at least one of the drawbacks present in the prior art. More particularly, the invention has for technical problem to provide a piezoelectric sensor in piezoelectric actuation device after it has been fabricated without changing the manufacturing process.

Technical solution

[0007] The first object of the invention is directed to a piezoelectric device shaped as a tridimensional object with at least two surfaces, wherein said piezoelectric device comprises a first set of two or more electrodes. Said piezoelectric device is remarkable in that at least one of the surfaces which is free of electrodes from said first set of two or more electrodes is covered with at least a second set of electrodes.

[0008] According to a preferred embodiment, said second set of electrodes is made of at least two interdigitated electrodes.

[0009] According to a preferred embodiment, said second set of electrodes is made of at least two electrodes distributed along a single conductive line.

[0010] According to a preferred embodiment, said interdigitated electrodes are on two distinct surfaces of said piezoelectric device.

[0011] According to a preferred embodiment, said piezoelectric device is made of a ceramic material, preferentially of the perovskite structure and even more preferentially made of lead zirconate titanate or $LiNbO_3$.

[0012] According to a preferred embodiment, said second set of electrodes is made of at least one electrical conductor comprising electrically conductive nanoparticles, preferentially nanoparticles made of silver, gold, copper, aluminium or indium tin oxide, alias ITO.

[0013] According to a preferred embodiment, said interdigitated electrodes are spaced from each other with a gap comprised between 10 µm and 100 µm.

[0014] According to a preferred embodiment, the electric conductors constituting said interdigitated electrodes have a width comprised between 5 µm and 1 mm, preferentially between 20µm and 100µm.

[0015] According to a preferred embodiment, said piezoelectric device is a pyroelectric device.

[0016] According to a preferred embodiment, said piezoelectric device is a multi-layer piezoelectric device, comprising alternating dielectric layers and metallic layers, the number of metallic layers being equal to n and the number of piezoelectric layers being equal to n+1, n being an integer.

[0017] According to a preferred embodiment, said metallic layers are made of metallic electrodes, preferably of interdigitated metallic electrodes, more preferably of interdigitated nickel or platinum of palladium *electrodes*.

[0018] According to a preferred embodiment, said electrodes of said second set of electrodes are planar.

[0019] The second object of the invention is directed to a method for measuring the behaviour of a piezoelectric device, said method comprising the steps of

a. providing a piezoelectric device with a first set of two or more electrodes, said piezoelectric device being shaped as tridimensional object with at least two surfaces,
b. printing at least a second set of electrodes on at least one of the faces which is free of electrodes,
c. determining the variation of the electrical charges on said second set of electrodes.

[0020] According to a preferred embodiment, said second set of electrode is made of at least two interdigitated electrodes.

[0021] According to a preferred embodiment, said second set of electrode is made of at least two electrodes distributed along a single conductive line.

[0022] According to a preferred embodiment, said printing is performed on at least two distinct surfaces of said piezoelectric device.

[0023] According to a preferred embodiment, said step (b) is performed by inkjet printing.

[0024] According to a preferred embodiment, said step (b) is performed by aerosol printing.

[0025] According to a preferred embodiment, said step (b) is performed with an ink made of electrically conductive nanoparticles.

[0026] According to a preferred embodiment, said ink made of electrically conductive nanoparticles is an ink made of silver, gold, copper, aluminium or indium tin oxide, alias ITO.

Advantages of the invention

[0027] The invention is particularly interesting in that piezoelectric actuator can be functionalized with piezoelectric sensor by simple deposition of the sensor onto the piezoelectric actuator, namely by inkjet printing or aerosol printing. This enables the functionalization of every type of piezoelectric device, without addition of any material not being part of the device.

[0028] Isolation galvanic can be achieved because the second set of electrodes is not necessarily in contact with the first set of electrodes.

[0029] The space occupation of the printed sensor is negligible compared to the size of the piezoelectric actuator, due to the low thickness of the second set of electrodes.

[0030] Moreover, the outer surface of the piezoelectric layer, which before was of no or few utility, because requiring any kind of activation in order to bond or glue any further element is now of great use, since it is the same dielectric material which is printed by the interdigitated electrodes.

Brief description of the drawings

[0031] Figure 1 shows a representation of a mechanical deformation sensor with a cylindrical shape and with an interdigital capacitor as a *deposited sensor*, in accordance with the present invention.

[0032] Figure 1A shows a representation of a mechanical deformation sensor with a cuboid shape and with a piece of conductor as a *deposited sensor*, in accordance with the present invention.

[0033] Figure 2 shows a representation of a mechanical deformation sensor with a cuboid shape and with an interdigital capacitor as a *deposited sensor*, in accordance with the present invention.

[0034] Figure 2A shows a representation of a mechanical deformation sensor with a cylindrical shape and with a piece of conductor as a *deposited sensor*, in accordance with the present invention.

[0035] Figure 3 shows a representation of a multilayer capacitor device in accordance with the present invention.

Description of an embodiment

[0036] The principle of the invention is to deposit on a piezoelectric actuator a sensor, so-called *deposited sensor*, which will be used to measure the deformation of the piezoelectric actuator.

[0037] The piezoelectric actuator 10 is typically a device made of piezoelectric material, preferentially ceramic material. Those materials have also dielectric properties. The crystal structure of the ceramic material can be the perovskite structure. For example, such material can be lead zirconate titanate (PZT) or lithium niobate ($LiNbO_3$). Two electrodes (8a, 8b), that are used to actuate said piezoelectric actuator, are connected to one part of the piezoelectric actuator, either on the same face (as shown on figure 1 or 2) or on two distinct faces (not represented).

[0038] As shown in figure 1 or 2, the two electrodes (8a, 8b) consist respectively in a positive electrode and in a negative electrode. The positive electrode 8a (as indicated on the figures) can be interchanged with the negative electrode 8b.

[0039] The piezoelectric actuator (when electric charges are displaced in a solid in response to an applied mechanical stress) can also be a pyroelectric sensor (when electric charges are displaced in a solid in response to a variation of temperature).

[0040] The *deposited sensor* can be an interdigital capacitor 6 (see figures 1 and 2), or a piece of conductor 60 (see figures 1A and 2A), preferentially planar, which is deposited on one face of the piezoelectric device which is free of electrode, preferentially on the outer surface of the piezoelectric actuator, by a special deposition method, which is printing, preferentially inkjet printing or aerosol printing. This particular deposition method allows for the use of every kind of shape of the piezoelectric actuator, since printing, or inkjet printing, or aerosol printing, can be achieved on every kind of tri-dimensional shape.

[0041] When the piezoelectric actuator comprised a printed *deposited sensor*, a mechanical deformation sensor has been developed.

[0042] When the piezoelectric actuator comprised a printed *deposited sensor*, a temperature sensor has also been developed.

[0043] The *deposited sensor* can be realized on every free surface of the piezoelectric actuator as it functions completely independently from the electrodes of the piezoelectric actuator. Isolation galvanic is thus reached when the electrodes of the piezoelectric actuator are not connected to any of the electrodes of the *deposited sensor.*

[0044] In the case the *deposited sensor* is an interdigitated capacitor, it has two electrodes, a first electrode 6a and a second electrode 6b, each of them being interdigitated with the other (see figures 1 or 2). Each of said two electrodes is made for example of silver, which is a highly electrical conductive component (6.30×10^7 S/m at 20°C). Alternatively, gold (4.10×10^7 S/m at 20°C) or copper (5.96×10^7 S/m at 20°C) can be used. Alternatively, every electrically conductive component which has a conductivity superior to 10^6 S/m and is printable may be used.

[0045] Each of the two electrodes (6a, 6b) has a plurality of extending electrodes (6c and 6d). The first extending electrodes 6c of the first electrode 6a are provided interlaced with the plurality of second extending electrodes 6d of the second electrode 6b.

[0046] The two electrodes (6a, 6b) forming the interdigital capacitor 6 are spaced from each other by a gap which is comprised between 10 µm and 100 µm, *i.e.* the pitch between a first extending electrode 6c and a second extending electrode 6d is comprised between 10 µm and 100 µm.

[0047] The width/size of the two electrodes forming the interdigital capacitor, *i.e.* the interlaced overlapping length of the first extending electrode 6c and the second extending electrode 6d is comprised between 5 µm and 1 mm. Preferentially, the width is comprised between 20 µm and 100 µm.

[0048] The thickness of the interdigital capacitor is as low as 1 µm, thereby reducing considerably the space occupation of the sensing structure compared to the size of the piezoelectric device. This has the advantages of allowing for the wide use of such device, since they present a compact form.

[0049] In the case the *deposited sensor* is a conductor line 60, it can be made of a straight line of conducting material with two or four pads 65 for contacts (see figure 1A). The conductive line 60 and the contact pads 65 are made for example of silver, which is a highly electrical conductive component (6.30×10^7 S/m at 20°C). Alternatively, gold (4.10×10^7 S/m at 20°C) or copper (5.96×10^7 S/m at 20°C) can be used. Alternatively, every electrically conductive component which has a conductivity superior to 10^6 S/m and is printable may be used. This conductive line 60 can also be a meander, as displayed in figure 2A.

[0050] The width of the conductive line 60 can be typically between 10 and 1 mm, preferably between 10 and 100 µm. The length of the line can be between 50 µm and 1 cm, preferably between 200 µm and 1 mm.

[0051] The thickness of the conductive line can as low as 1 µm, thereby reducing considerably the space occupation of the sensing structure compared to the size of the piezoelectric device. This has the advantages of allowing for the wide use of such device, since they present a compact form.

[0052] The piezoelectric device can also be a multilayer capacitor device 100 (MLC), where metallic electrodes 2 and piezoelectric layers 4 alternate (see figure 3). The condition for depositing the *sensor* of the present invention is that the outer layer of the piezoelectric actuator must be made of dielectric material, preferentially ceramic material such as lead zirconate titanate (PZT), so that the metallic layer or layers (*e.g.*, electrodes in silver) remains electrically isolated from the inner electrodes of the MLC. Inside the MLC, the metallic layers alternate with the dielectric layers and that the number of metallic layers is equal to n while the number of dielectric layer is equal to n+1 (n being an integer).

[0053] In a practical case, let's consider the top layer (which is a free surface, namely free of any electrodes) of the piezoelectric actuator 100. The dimensions of the piezoelectric device 100 are for example 5 mm × 5 mm × 2.4 mm in the case where the piezoelectric device is with a shape of a polyhedron with six faces. The piezoelectric device comprises two electrodes (8a, 8b) on two distinct faces, preferably on two distinct opposed faces. The electrodes (8a, 8b) can also been present on two distinct faces, which are not necessarily two opposed faces (not shown on figure 3). The inkjet/aerosol printing of silver electrode(s) is performed on the free surface (see figure 3). The pattern of these electrodes (6, 60) can be either interdigitated, similar to figures 1 and 2, or a conductive line 60 similar to figures 1A or 2A. This deposition is usually followed by an annealing step that is used to dry and sinter the metallic nanoparticles of silver ink (this can also be achieved with gold or copper nanoparticles). This annealing step enables electric conductivity. The annealing step has been performed at 200°C during 30 minutes at atmospheric pressure.

[0054] The electric field applied between the two electrodes (8a, 8b) of the piezoelectric actuator 100 induces a mechanical deformation into the whole actuator. This deformation is detected by the *deposited sensor*. If the latter is made of interdigitated electrodes 6, the deformation is sensed via the piezoelectric effect that will induce charge movement that can be detected via an LCR-meter or an oscilloscope (not shown) connected between the electrodes (6a,6b) of the interdigitated capacitor. If the sensor is a conductive line 60, the deformation is sensed via the variation of resistance of the conductive line (piezoresistive effect). This resistance can be measured when a dc current is applied to the two external pads 65a in figures 1A or 2A, and then one measures the resulting voltage between the two inner contact pads 65b displayed in figures 1A or 2A. This gives information on the actuator device 100.

[0055] Such data on the actuator device are very interesting and can be adapted in implementation such as high resolution microscopy, any application requiring monitoring the displacement of an object preferably on the micrometer scale, a piezoelectric transformer. Fatigue monitoring system, strain sensor, temperature sensor and humidity sensor are achievable thanks to the functionalisation of a piezoelectric device, namely thanks to the mechanical deformation sensor of the present invention.

Revendications

1) Dispositif piézo-électrique (10, 100) en forme d'objet tridimensionnel avec au moins deux surfaces,
dans lequel ledit dispositif piézoélectrique (10, 100) comprend un premier ensemble de deux électrodes ou plus (8a, 8b),
caractérisé en ce que
au moins une des surfaces qui est dépourvue d'électrodes provenant dudit premier ensemble de deux électrodes ou plus (8a, 8b) est recouverte d'au moins un second ensemble d'électrodes (6, 60).

2) Dispositif piézoélectrique (10, 100) selon la revendication 1, caractérisé en ce que ledit second ensemble d'électrodes est constitué d'au moins deux électrodes interdigitées (6a, 6b).

3) Dispositif piézoélectrique (10, 100) selon la revendication 1, caractérisé en ce que ledit second ensemble d'électrodes est constitué d'au moins deux électrodes réparties le long d'une seule ligne conductrice (60).

4) Dispositif piézoélectrique (10, 100) selon la revendication 2, caractérisé en ce que lesdites électrodes interdigitées (6a, 6b) sont sur deux surfaces distinctes dudit dispositif piézoélectrique (10).

5) Dispositif piézoélectrique (10, 100) selon l'une quelconque des revendications 1 à 4, caractérisé en ce que ledit dispositif piézoélectrique (10, 100) est réalisé en un matériau céramique, préférentiellement de la structure pérovskite et encore plus préférentiellement en zirconate de plomb titanate ou en $LiNbO_3$.

6) Dispositif piézoélectrique (10, 100) selon l'une quelconque des revendications 1 à 5, caractérisé en ce que ledit second ensemble d'électrodes (6, 60) est constitué d'au moins un conducteur électrique comprenant des nanoparticules électriquement conductrices, préférentiellement des nanoparticules en argent, or, cuivre, aluminium ou oxyde d'indium et d'étain, alias ITO.

7) Dispositif piézoélectrique (10, 100) selon l'une quelconque des revendications 2 ou 4 à 6, caractérisé en ce que lesdites électrodes interdigitées (6a, 6b) sont espacées l'une de l'autre avec un intervalle compris entre 10 μm et 100 μm.

8) Dispositif piézoélectrique (10, 100) selon l'une quelconque des revendications 6 à 7, caractérisé en ce que les conducteurs électriques constituant lesdites électrodes interdigitées (6a, 6b) ont une largeur comprise entre 5 μm et 1 mm, préférentiellement entre 20 μm et 100 μm.

9) Dispositif piézoélectrique (10, 100) selon l'une quelconque des revendications 1 à 8, caractérisé en ce que ledit dispositif piézoélectrique (10, 100) est un dispositif pyroélectrique.

10) Dispositif piézoélectrique (100) selon l'une quelconque des revendications 1 à 9, caractérisé en ce que ledit dispositif piézoélectrique (100) est un dispositif piézoélectrique multicouche, comportant des couches diélectriques alternées et des

couches métalliques, le nombre de couches métalliques étant égal à n et le nombre de couches piézoélectriques étant égal à $n + 1$, n étant un nombre entier.

11) Dispositif piézo-électrique (100) selon la revendication 10, caractérisé en ce que lesdites couches métalliques sont constituées d'électrodes métalliques, de préférence d'électrodes métalliques interdigitées, plus préférentiellement d'électrodes interdigitées en nickel ou en platine ou en palladium.

12) Dispositif piézoélectrique (10, 100) selon l'une quelconque des revendications 1 à 11, caractérisé en ce que lesdites électrodes (6, 60) dudit second ensemble d'électrodes sont planes.

13) Méthode de mesure du comportement d'un dispositif piézoélectrique (10, 100), ladite méthode comprenant les étapes de:

a) mise à disposition d'un dispositif piézoélectrique avec un premier ensemble de deux électrodes ou plus, ledit dispositif piézoélectrique étant en forme d'un objet tridimensionnel avec au moins deux surfaces,
b) impression d'au moins un second ensemble d'électrodes sur au moins une des faces qui est dépourvue d'électrodes,
c) détermination de la variation des charges électriques sur ledit second ensemble d'électrodes.

14) Méthode selon la revendication 13, caractérisée en ce que ledit second ensemble d'électrodes est constitué d'au moins deux électrodes interdigitées (6a, 6b).

15) Méthode selon la revendication 13, caractérisée en ce que ledit second ensemble d'électrodes est constitué d'au moins deux électrodes réparties le long d'une seule ligne conductrice (60).

16) Méthode selon les revendications 13-14, dans laquelle ladite impression est réalisée sur au moins deux surfaces distinctes dudit dispositif piézoélectrique.

17) Méthode selon l'une quelconque des revendications 13 à 16, dans laquelle ladite étape (b) est réalisée par impression jet d'encre.

18) Méthode selon l'une quelconque des revendications 13 à 16, dans laquelle ladite étape (b) est réalisée par impression par aérosol.

19) Méthode selon l'une quelconque des revendications 13 à 18, dans laquelle ladite étape (b) est réalisée avec une encre faite de nanoparticules électriquement conductrices.

20) Méthode selon la revendication 19, dans laquelle ladite encre constituée de nanoparticules électriquement conductrices est une encre faite d'argent, d'or, de cuivre, d'aluminium ou d'oxyde d'indium et d'étain, alias ITO.

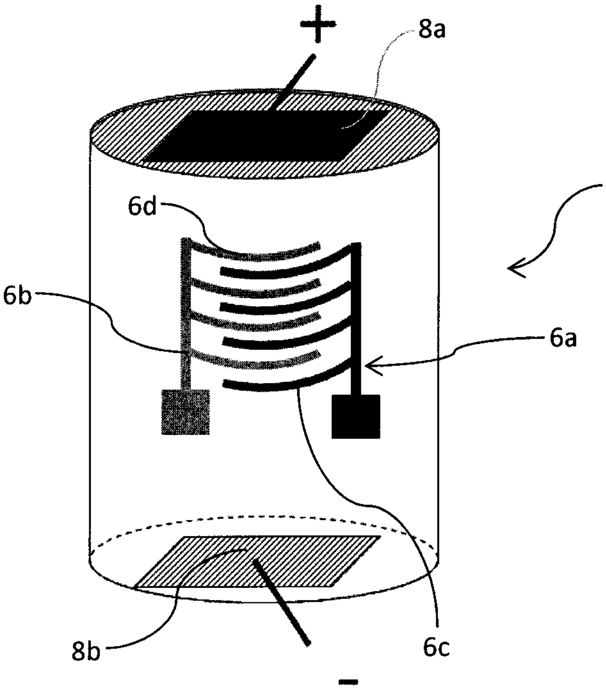


Fig. 1

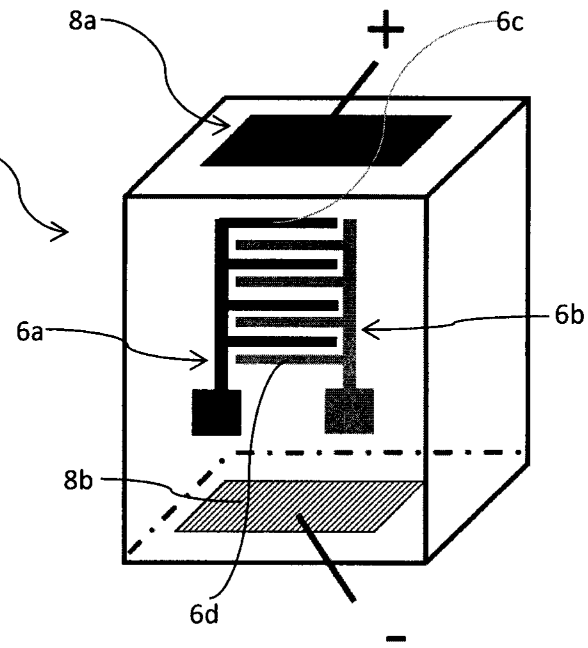


Fig. 2

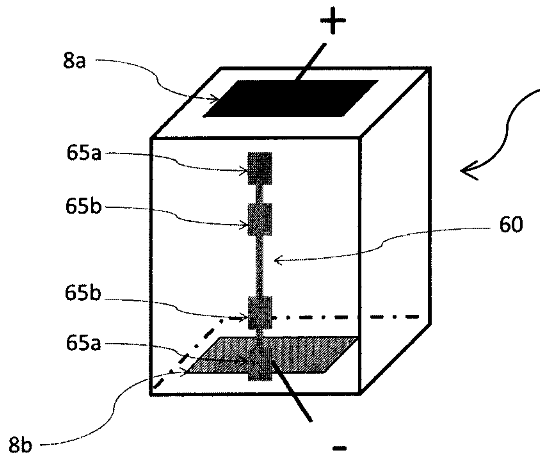


Fig. 1A

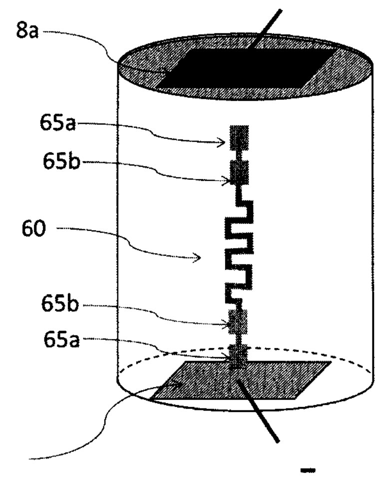


Fig. 2A

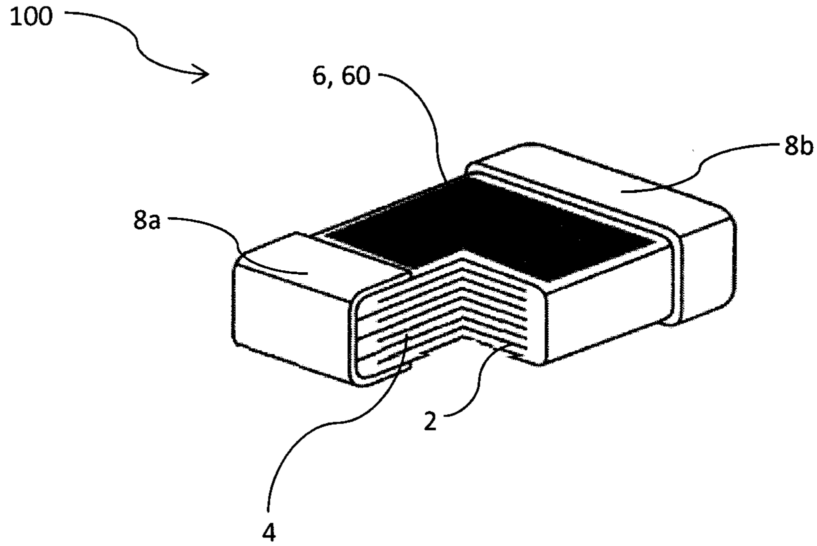


Fig.3

Abstract

The first object of the invention is directed to a piezoelectric device (10) shaped as a tridimensional object with at least two surfaces, wherein said piezoelectric device (10) comprises a first set of two or more electrodes (8a, 8b). Said piezoelectric device (10) is remarkable in that at least one of the surfaces which is free of electrodes from said first set of two or more electrodes (8a, 8b) is covered with at least a second set of electrodes. The second object of the invention is directed to a method for measuring the behaviour of a piezoelectric device.

(Figure 1)

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SEARCH REPORT

in accordance with Article 35.1 a)
of the Luxembourg law on patents
dated 20 July 1992

National Application Number

LO 1854
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The present search report has been drawn up for all claims

1

	Date of completion of the search	Examiner
	31 August 2018	Steiner, Markus

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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ANNEX TO THE SEARCH REPORT ON LUXEMBOURG PATENT APPLICATION NO.

LO 1854
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This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
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CN 103943772 B	22-06-2016	NONE	

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

LE GOUVERNEMENT
DU GRAND-DUCHÉ DE LUXEMBOURG
Ministère de l'Économie

WRITTEN OPINION

File No.	Filing date *(day/month/year)*	Priority date *(day/month/year)*	Application No.
LO1854	22.12.2017		LU100594
International Patent Classification (IPC) INV. H01L41/047 H01L41/08 H01L41/083 H01L41/29			
Applicant Luxembourg Institute of Science and Technology (LIST)			

This report contains indications relating to the following items:

- ☒ Box No. I — Basis of the opinion
- ☐ Box No. II — Priority
- ☐ Box No. III — Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
- ☐ Box No. IV — Lack of unity of invention
- ☒ Box No. V — Reasoned statement with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
- ☐ Box No. VI — Certain documents cited
- ☒ Box No. VII — Certain defects in the application
- ☒ Box No. VIII — Certain observations on the application

Examiner

Steiner, Markus

Application No.
LU100594

WRITTEN OPINION

Box No. I Basis of the opinion

1. This opinion has been established on the basis of the latest set of claims filed before the start of the search.

2. With regard to any **nucleotide and/or amino acid sequence** disclosed in the application and necessary to the claimed invention, this opinion has been established on the basis of:

   a. type of material:

   ☐ a sequence listing

   ☐ table(s) related to the sequence listing

   b. format of material:

   ☐ on paper

   ☐ in electronic form

   c. time of filing/furnishing:

   ☐ contained in the application as filed.

   ☐ filed together with the application in electronic form.

   ☐ furnished subsequently.

3. ☐ In addition, in the case that more than one version or copy of a sequence listing and/or table relating thereto has been filed or furnished, the required statements that the information in the subsequent or additional copies is identical to that in the application as filed or does not go beyond the application as filed, as appropriate, were furnished.

4. Additional comments:

Box No. V Reasoned statement with regard to novelty, inventive step and industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty	Yes:	Claims	3, 6-8, 15, 17-20
	No:	Claims	1, 2, 4, 5, 9-14, 16
Inventive step	Yes:	Claims	3, 15
	No:	Claims	1, 2, 4-14, 16-20
Industrial applicability	Yes:	Claims	1-20
	No:	Claims	

2. Citations and explanations

   see separate sheet

WRITTEN OPINION

Box No. VII Certain defects in the application

The following defects in the form or contents of the application have been noted:

see separate sheet

Box No. VIII Certain observations on the application

see separate sheet

Re Item V

1 Reference is made to the following documents:

D1 : DE 11 2015 001 953 T5
D2 : CN 102820422 A
D3 : DE 10 2006 047 411 A1
D4 : US 2015/007699 A1
D5 : DE 103 45 730 A1
D6 : EP 1 705 016 A

2 The present application does not meet the criteria of patentability, because the subject-matter of independent claims 1 and 13 is not novel.

2.1 Document D1 shows a piezoelectric device (which is always "shaped as a tridimensional object" - only the surfaces of a device are two-dimensional) with multiple surfaces, comprising a first set of two electrodes and a second set of electrodes provided on a surface which is free from the first set of electrodes (see fig 4 with para. [0035]).

Such a device can also be seen in D2 (figs. 1-4, paras. [0037]-[0043]), D3 (figs. 2, 3, para. [0047]), D4 (figs. 1, 2, paras. [0038]-[0043]) and D5 (figs. 1, 2, 6, 7, paras. [0029], [0030], [0034]).

The subject-matter of claim 1 is therefore not novel.

2.2 Furthermore, claims 2- 12 do not add any features which would render the subject-matter of the claims they are dependent on novel or inventive, the reasons being the following:

D2 - D4 show an arrangement with interdigitated electrodes being on distinct (in this case opposite) surfaces [claims 2, 4].

The device is made of a ceramic material (PZT) [claim 5].

Electrodes made of electrical conductors comprising electrically conductive nanoparticles are well known in the art (see D6, para. [0028]) [claim 6].

Although none of the documents show the size and spacing of the interdigitated electrodes, this is considered to be a mere (non-inventive) design-option, in particular also because of the large ranges claimed [claims 7, 8]

A piezoelectric device is always (by nature of the material properties) to some extent also a pyroelectric device [claim 9].

D5 shows a multilayer piezoelectric device, such devices always having one more piezoelectric layer than planar internal metallic electrodes [claims 10-12].

2.3 The objections raised above apply in kind for the method claims 13-20, the reasons being as follows:

Printing is a common method for manufacturing electrode on piezoelectric ceramics and is shown, for example, in D2, starting from para. [0058]. Aerosol printing or inkjet printing are commonly employed methods of printing and thus also not inventive. The features of the remaining claims are discussed above.

Re Item VII

3 The relevant background art disclosed in the above-mentioned documents is not mentioned in the description, nor are these documents identified therein.

Re Item VIII

4 Claim 15 (and consequently also claim 3) is not clear.

Claim 15 is dependent on claim 13 which requires that the method includes determining the variation of electrical charges on the second set of electrodes. According to claim 15 (and claim 3), however, this second set of electrodes is made of at least two electrodes distributed along a single conductive line which would imply that the at least two electrode are at the same potential, thus preventing any detectable charge variation.

CN102820422 A 20121212

The present invention provides a kind of monolithic piezoelectric transducer and preparation method thereof.This transducer comprises piezoelectric patches, and the upper and lower surfaces of piezoelectric patches is respectively arranged with first and drives the interdigital electrode and the second driving interdigital electrode; The upper and lower surfaces of piezoelectric patches also is respectively arranged with the first earthy interdigital electrode and the second ground connection interdigital electrode, and the first ground connection interdigital electrode and the second ground connection interdigital electrode are electrically connected, and constitutes the common ground electrode; Piezoelectric patches drives interdigital electrode, second and drives under the direct voltage effect of interdigital electrode and common ground electrode through being applied to first, forms the cross polarization zone respectively at the upper surface piezoelectric layer and the lower surface piezoelectric layer of piezoelectric patches.PZT (piezoelectric transducer) provided by the invention is simple in structure; It is convenient to realize, can be used as flexural piezoelectric motion driver and use, otherwise or can be used as transducer; Curved vibration or curved displacement that induction sound wave, pressure, vibration, acceleration etc. produce, and PZT (piezoelectric transducer) can be worked under high low temperature adverse circumstances.

Monolithic piezoelectric transducer and preparation method thereof

Technical field

The present invention relates to the piezoelectric device technology, relate in particular to a kind of monolithic piezoelectric transducer that is operated in end compression electricity, curved motor pattern and preparation method thereof.

Background technology

PZT (piezoelectric transducer) be utilize piezoelectric just, the intelligent device made of inverse piezoelectric effect; Have that size is little, good linearity, convenient, the characteristics such as displacement resolution is high, frequency response good, energy consumption is low, noiseless of control, obtained extensive use at high-technology fields such as precision optics, micromachine, microelectric techniques.

At present; As rigid displacement driver common in the PZT (piezoelectric transducer); Mainly comprise multiple field driver, rainbow formula (Rainbow) driver, month dentition formula (Moonie) driver, cymbals formula (Cymbals) driver and single (two) crystal chip driver etc., wherein, the bearing capacity of multiple field driver is big; But complex manufacturing technology, displacement is little; In order to obtain bigger displacement; PZT (piezoelectric transducer) generally is designed and is operated in a curved-motor pattern; For example common Rainbow driver, Moonie driver and Cymbals driver etc.; PZT (piezoelectric transducer) can zoom into the bending displacement that flexure strip is big with the micro-displacement that piezoelectrics produce through a curved-pattern. But a curved-motor pattern transducer architecture is comparatively complicated;Single (two) crystal chip driver of tradition is that one or two piezoelectric patches and a metallic elastic sheet are combined into cantilever beam structure, through the asymmetric stretch of piezoelectric patches along y direction, directly obtains bigger bending displacement.This transducer has advantages such as simple in structure, that displacement is big; But their making need be used organic binder bond different flaky materials are combined with each other; Be unwell to extreme severe rugged environment; For example the high and low temperature environment uses down, and what utilize is horizontal low tension coefficient d 31 pattern work, the Piezoelectric Driving poor-performing.

To sum up, existing piezoelectric actuator adopts layer structure usually, the complex structure of piezoelectric device, and complex manufacturing technology, cost of manufacture is high; Simultaneously, the bound fraction restriction because of layer structure causes the adaptability of piezoelectric actuator environment relatively poor, and particularly high temperature or low temperature environment use down and be restricted.

Summary of the invention

The present invention provides a kind of monolithic piezoelectric transducer and preparation method thereof; Can effectively overcome complex structure and the relatively poor defective of environmental suitability that existing layer structure piezoelectric device exists; Can simplify the structure and the manufacture craft of PZT (piezoelectric transducer), make PZT (piezoelectric transducer) have better environmental suitability.

The present invention provides a kind of monolithic piezoelectric transducer, comprising:

Piezoelectric patches, the upper surface of said piezoelectric patches and lower surface are respectively arranged with first and drive the interdigital electrode and the second driving interdigital electrode, and the said first driving interdigital electrode and second drives interdigital electrode and is symmetrical set up and down;

The upper surface of said piezoelectric patches and lower surface also are respectively arranged with the first earthy interdigital electrode and the second ground connection interdigital electrode; The said first ground connection interdigital electrode and the second ground connection interdigital electrode are arranged in a crossed manner relatively with the said first driving interdigital electrode and the second driving interdigital electrode respectively at the upper surface and the lower surface of said piezoelectric patches; And the said first ground connection interdigital electrode and the second ground connection interdigital electrode are electrically connected through the side electrode of said piezoelectric patches, constitute the common ground electrode;

Said piezoelectric patches drives interdigital electrode, second and drives under the direct voltage effect of interdigital electrode and common ground electrode through being applied to said first, forms the cross polarization zone respectively at the upper surface piezoelectric layer and the lower surface piezoelectric layer of said piezoelectric patches.

In the above-mentioned monolithic piezoelectric transducer, the voltage that is applied on the said common ground electrode is earthed voltage V3=0, and the voltage that is applied to the said first driving interdigital electrode is V1, and the voltage that is applied to the said second driving interdigital electrode is V2.

Above-mentioned monolithic piezoelectric transducer can be used as piezoelectric actuator; Under the driving voltage effect that is applied on the said first driving interdigital electrode and the second driving interdigital electrode; Upper surface piezoelectric layer through said piezoelectric patches and vertical piezoelectric d 33 patterns of lower surface piezoelectric layer and along the asymmetric strain of the upper surface and the lower surface of y direction make said piezoelectric patches produce flexural vibrations or curved displacement along thickness direction.

Above-mentioned monolithic piezoelectric transducer also can be used as sonic test transducer, pressure test transducer, vibration-testing transducer or acceleration test transducer.

The present invention also provides a kind of manufacture method of monolithic piezoelectric transducer, comprising:

Upper surface at piezoelectric patches is provided with the first driving interdigital electrode and the first ground connection interdigital electrode; Lower surface at said piezoelectric patches is provided with the second driving interdigital electrode and the second ground connection interdigital electrode; Wherein, The said first driving interdigital electrode and second drives interdigital electrode and is symmetrical set up and down, and the said first ground connection interdigital electrode and the second ground connection interdigital electrode are arranged in a crossed manner relatively with the said first driving interdigital electrode and the second driving interdigital electrode respectively at the upper surface and the lower surface of said piezoelectric patches;

The said first ground connection interdigital electrode and the second ground connection interdigital electrode side electrode through said piezoelectric patches is electrically connected, constitutes the common ground electrode;

Drive interdigital electrode, the second driving interdigital electrode and common ground electrode said first and apply direct voltage; Upper surface piezoelectric layer and lower surface piezoelectric layer to said piezoelectric patches carry out cross polarization, make the upper surface piezoelectric layer of said piezoelectric patches and lower surface piezoelectric layer form the cross polarization zone respectively.

In the manufacture method of above-mentioned monolithic piezoelectric transducer; At the upper surface and the lower surface of said piezoelectric patches, make first through modes such as sputter or printings respectively and drive interdigital electrode, second driving interdigital electrode, the first ground connection interdigital electrode and the second ground connection interdigital electrode.

In addition, the present invention also provides a kind of monolithic piezoelectric transducer, comprising:

Piezoelectric patches, the upper surface of said piezoelectric patches and lower surface are respectively arranged with first and drive the interdigital electrode and the second ground connection interdigital electrode, and the said first driving interdigital electrode and the second ground connection interdigital electrode are symmetrical set up and down;

The upper surface of said piezoelectric patches and lower surface also are respectively arranged with the first ground connection interdigital electrode and second and drive interdigital electrode; It is arranged in a crossed manner relatively with the said first driving interdigital electrode and the second ground connection interdigital electrode respectively at the upper surface and the lower surface of said piezoelectric patches that the said first ground connection interdigital electrode and second drives interdigital electrode, and said first ground connection interdigital electrode and second ground connection interdigital electrode formation common ground electrode;

Said piezoelectric patches drives interdigital electrode, second and drives under the direct voltage effect of interdigital electrode and common ground electrode through being applied to said first, forms the cross polarization zone respectively at the upper surface piezoelectric layer and the lower surface piezoelectric layer of said piezoelectric patches.

Correspondingly, the present invention also provides a kind of manufacture method of monolithic piezoelectric transducer, comprising:

Upper surface at piezoelectric patches is provided with the first driving interdigital electrode and the first ground connection interdigital electrode; Lower surface at said piezoelectric patches is provided with the second driving interdigital electrode and the second ground connection interdigital electrode; Wherein, The said first driving interdigital electrode and the second ground connection interdigital electrode are symmetrical set up and down; It is arranged in a crossed manner relatively with the said first driving interdigital electrode and the second ground connection interdigital electrode respectively at the upper surface and the lower surface of said piezoelectric patches that the said first ground connection interdigital electrode and second drives interdigital electrode, and the said first ground connection interdigital electrode and the second ground connection interdigital electrode constitute the common ground electrode;

Drive interdigital electrode, the second driving interdigital electrode and common ground electrode said first and apply direct voltage; Upper surface piezoelectric layer and lower surface piezoelectric layer to said piezoelectric patches carry out cross polarization, make the upper surface piezoelectric layer of said piezoelectric patches and lower surface piezoelectric layer form the cross polarization zone respectively.

Monolithic piezoelectric transducer provided by the invention adopts individual layer piezoelectric patches structure; Through making interdigital electrode on the piezoelectric patches surface; And carry out cross polarization, can make piezoelectric patches upper and lower surfaces layer be operated in vertical piezoelectric d 33 patterns, and can be flexible along piezoelectric patches y direction antisymmetry; The twin lamella PZT (piezoelectric transducer) that works in horizontal piezoelectric d 31 patterns that this is traditional relatively can more effective generation flexural vibrations or curved displacement during as driver; Because it is much little that the capacitance of the relative layer structure of interdigital electrode structure of piezoelectric patches is wanted, the power that under equal driven condition, is consumed can be still less;Simultaneously, during as transducer, the interdigital electrode of piezoelectric patches upper and lower surfaces can produce a pair of differential output signal under the bending strain effect, thereby has higher sensing sensitivity; In addition, because the monolithic piezoelectric transducer provided by the invention piezoelectricity single chip architecture that is non-stratiform, so have advantage such as better variation of ambient temperature adaptability.PZT (piezoelectric transducer) provided by the invention is simple in structure, and is easy to make, can effectively reduce cost of manufacture, need not use simultaneously the not material of high-and low-temperature resistance such as organic binder bond in traditional sandwich construction, can more effectively under adverse circumstances such as high low temperature, work.

Description of drawings

The volume rendering structural representation of the PZT (piezoelectric transducer) that Fig. 1 provides for the embodiment of the invention one;

Fig. 2 is the upper surface electrode distribution schematic diagram of PZT (piezoelectric transducer) among Fig. 1;

Fig. 3 is the lower surface electrode distribution schematic diagram of PZT (piezoelectric transducer) among Fig. 1;

Fig. 4 A is a kind of sketch map that the crossed electrode along the length direction of piezoelectric patches that produced in upper surface piezoelectric layer and the lower surface piezoelectric layer of piezoelectric patches in the embodiment of the invention divides cloth;

Fig. 4 B is the another kind of sketch map that the crossed electrode along the length direction of piezoelectric patches that produced in upper surface piezoelectric layer and the lower surface piezoelectric layer of piezoelectric patches in the embodiment of the invention divides cloth;

The bending deformation sketch map that the PZT (piezoelectric transducer) that Fig. 5 provides for the embodiment of the invention produces under driven;

The volume rendering structural representation of the PZT (piezoelectric transducer) that Fig. 6 provides for the embodiment of the invention two;

Fig. 7 is the upper surface electrode distribution schematic diagram of PZT (piezoelectric transducer) among Fig. 6;

Fig. 8 is the lower surface electrode distribution schematic diagram of PZT (piezoelectric transducer) among Fig. 6;

The manufacture method schematic flow sheet of the PZT (piezoelectric transducer) that Fig. 9 provides for the embodiment of the invention three;

The manufacture method schematic flow sheet of the PZT (piezoelectric transducer) that Figure 10 provides for the embodiment of the invention four.

Embodiment

The volume rendering structural representation of the PZT (piezoelectric transducer) that Fig. 1 provides for the embodiment of the invention one; Fig. 2 is the upper surface electrode distribution schematic diagram of PZT (piezoelectric transducer) among Fig. 1; Fig. 3 is the lower surface electrode distribution schematic diagram of PZT (piezoelectric transducer) among Fig. 1.Like Fig. 1-shown in Figure 3; The present embodiment PZT (piezoelectric transducer) comprises piezoelectric patches 11; The upper surface of this piezoelectric patches 11 and lower surface are respectively arranged with first and drive the interdigital electrode 21 and the second driving interdigital electrode 22;And the first driving interdigital electrode 21 and second drives interdigital electrode 22 and is symmetrical set up and down, and promptly the first driving interdigital electrode 21 and second drives interdigital electrode 22 about being provided with in the face of title in the piezoelectric patches thickness; The upper surface of this piezoelectric patches 11 and lower surface also are respectively arranged with the first ground connection interdigital electrode 231 and the second ground connection interdigital electrode 232, and the first ground connection interdigital electrode 231 and the second ground connection interdigital electrode 232 to drive interdigital electrode 21 arranged in a crossed manner relatively with the second driving interdigital electrode 22 with two first of the upper and lower surface of piezoelectric patches respectively;The first ground connection interdigital electrode 231 and the second ground connection interdigital electrode 232 are electrically connected formation common ground electrode 23 through the side electrode 233 of piezoelectric patches 11; Piezoelectric patches 11 drives under the direct voltage effect of interdigital electrode 21, the second driving interdigital electrode 22 and common ground electrode 23 through being applied to first; Form the crossed electrode that is arc line type along piezoelectric patches 11 length directions respectively at the upper surface piezoelectric layer of piezoelectric patches 11 and lower surface piezoelectric layer and divide cloth, promptly form the cross polarization zone.The present embodiment PZT (piezoelectric transducer) is single piezoelectric patches structure; Can be used as piezoelectric actuator;Upper surface and lower surface through at piezoelectric patches are provided with interdigital electrode respectively, and form crossed electrodeization along its length on the surface of piezoelectric patches, like this; Be applied under the driving voltage effect that respectively drives interdigital electrode; The upper and lower piezoelectric layer of piezoelectric patches can be operated in vertical piezoelectric d 33 patterns, but along the asymmetric stretch of piezoelectric patches y direction, thereby can cause piezoelectric patches to produce the curved vibration or the flexural deformation of thickness direction.

It will be understood by those skilled in the art that above-mentioned interdigital electrode is on the main electrode, be distributed with a plurality of branch electrodes that the same direction in a plurality of edges is arranged, like the structure of the first driving interdigital electrode 21 among Fig. 2.In the present embodiment, the described first driving interdigital electrode 21 and the first ground connection interdigital electrode 231 are arranged in a crossed manner relatively, just are meant that two branch electrodes in the interdigital electrode are arranged in a crossed manner.

Fig. 4 A is a kind of sketch map that the crossed electrode along the length direction of piezoelectric patches that produced in upper surface piezoelectric layer and the lower surface piezoelectric layer of piezoelectric patches in the embodiment of the invention divides cloth.In the present embodiment; Between a pair of driving interdigital electrode on the upper and lower surface of piezoelectric patches 11 and a pair of common ground electrode, apply suitable direct voltage; Just can in the upper and lower surperficial piezoelectric layer of piezoelectric patches 11, form respectively, i.e. the crossed electrodeization of the length direction of piezoelectric patches along y direction; Particularly, can apply voltage V1 driving on the interdigital electrode 21, drive on the interdigital electrode 22 second and apply voltage V2 like first of Fig. 1-shown in Figure 3; On common ground electrode 23, apply voltage V3, and make V1=V2, V3=0;Be about to common ground electrode 23 ground connection; The first driving interdigital electrode 21 and second drives on the interdigital electrode 22 and applies identical voltage, like this, between each two adjacent interdigital electrode, will produce the electric polarization distribution that is arc shaped along y direction.Shown in Fig. 4 A, near the polarization in upper and lower surfaces zone, be in the other direction between each adjacent interdigital electrode, but their arc shape electric polarization is about piezoelectric patches thickness center line C-C ' symmetrical distribution in the piezoelectric patches.

Fig. 4 B is the another kind of sketch map that the crossed electrode along the length direction of piezoelectric patches that produced in upper surface piezoelectric layer and the lower surface piezoelectric layer of piezoelectric patches in the embodiment of the invention divides cloth.Different with above-mentioned Fig. 4 A is; When applying voltage formation crossed electrode; The voltage V1=-V2 that applies, like this, the arc-shaped electrode direction that forms at the upper and lower surfaces relative position of piezoelectric patches 11 is opposite; Promptly up and down in the piezoelectric layer arc shape electrode be to distribute about piezoelectric patches thickness center line C-C ' antisymmetry, shown in Fig. 4 B.

The present embodiment PZT (piezoelectric transducer) can be used as piezoelectric actuator and uses; Drive interdigital electrode 21, second and drive under the driving voltage effect of interdigital electrode 22 and common ground electrode 23 being applied to first, the piezoelectric patches driver can produce needed along thickness direction flexural deformation or length direction distortion.The driving voltage that facility is added in the first driving interdigital electrode 21 is V1, and the driving voltage that is applied to the second driving interdigital electrode 22 is V2, and common ground electrode 23 is generally the earth potential (zero potential) of driving voltage, is used for ground connection.

Under the polarization effect situation of the piezoelectric patches shown in Fig. 4 A, < 0, piezoelectric patches will extend so as if V1=V2; If V1=V2>0, piezoelectric patches will shorten so; If V1=-V2, or V1 ≠ V2, piezoelectric patches will be because of upper surface piezoelectric layer and the asymmetric strain of lower surface piezoelectric layer along y direction so, and the flexural deformation of generation thickness direction is as shown in Figure 5.The method of this asymmetric driving and generating bending strain because of having overcome the interface strain loss of layer structure transducer, can make piezoelectric actuator have the better driving effect.Therefore, if V1 and V2 are the alternating voltage that same-phase and amplitude equate, then piezoelectric patches will produce vibration along its length; If V1 and V2 are the alternating voltage (also pre-bias voltage can be arranged) of antiphase;Then piezoelectric patches will produce the curved vibration along thickness direction; Thus; Through selecting suitable V1 and V2 just can realize piezoelectric patches vibration along the longitudinal direction, or along the flexural vibrations of thickness direction, thereby realize the specific drive function of driver.

Similarly, under the polarization effect situation of the piezoelectric patches shown in Fig. 4 B, < 0, piezoelectric patches will extend so as if V1=-V2; If V1=-V2>0, piezoelectric patches will shorten so; If V1=V2, or V1 ≠-V2, then piezoelectric patches will produce the flexural deformation along thickness direction, and this is the bending strain method that another kind of asymmetric driving produces. Therefore, if during the alternating voltage that V1 and V2 are antiphase and amplitude to be equated, piezoelectric patches will produce along its length and vibrate; If when V1 and V2 were synchronous alternating voltage (also pre-bias voltage can be arranged), piezoelectric patches will produce the flexural vibrations along thickness direction, thereby can realize the bending strain specific drive function of piezoelectric actuator more easily.

Can find out, when the present embodiment PZT (piezoelectric transducer) uses as piezoelectric actuator, can utilize inverse piezoelectric effect, realize the certain variations and the vibrating function of piezoelectric actuator, convert electrical energy into mechanical energy being applied under the voltage effect that respectively drives interdigital electrode.Simultaneously, the piezoelectric patches in the PZT (piezoelectric transducer) is a single chip architecture, and cross polarization, and piezoelectric patches can work in vertical piezoelectric d 33 patterns.Because vertical piezoelectric coefficient d 33 of piezoelectric patches is the twice of horizontal piezoelectric coefficient d 31 normally, therefore, piezoelectric patches is operated under vertical piezoelectric d 33 patterns, has better Piezoelectric Driving performance, can obtain the better driving effect.

In addition, the present embodiment PZT (piezoelectric transducer) also can be used as sonic test transducer, pressure test transducer, vibration-testing transducer or acceleration test electric transducer, does the time spent when piezoelectric transducer receives external force; Because of bending strain can produce voltage, thereby, just can confirm the size of external force through detecting the size of voltage; Particularly, when using, the one or both ends of piezoelectric patches are fixed as piezoelectric transducer; And with common ground electrode 23 ground connection; The first driving interdigital electrode 21 and second drives interdigital electrode 22 and is connected to oscilloscope or potentiometer as signal output part respectively, applies multi-form and big or small external force at the other end or the middle part of piezoelectric patches, observes and also writes down the voltage output that is measured;According to the size of the magnitude of voltage that measures, just can obtain to be applied to the pressure size information on the piezoelectric patches. For ease of explanation, suppose first, to drive the voltage that interdigital electrode 21 places produce be V1 ', second drive the generation of interdigital electrode 22 places voltage be V2 ', the voltage that then produces under like Fig. 4 A or Fig. 4 B situation is explained as follows respectively.

When piezoelectric patches under the piezoelectric patches polarization effect situation shown in Fig. 4 A, if the external force that is applied to the piezoelectric patches other end can make piezoelectric patches produce compression or elongation strain, the voltage V1 '=V2 ' that then produces; That piezoelectric patches is produced is crooked if be applied to external force on the piezoelectric patches, and the voltage V1 ' and the V2 ' that then produce will equate, but phase place is opposite, promptly V1 '=-V2 '; If externally applied forces makes piezoelectric patches produce vibration along its length, then V1 ' and V2 ' equate and cyclic variation; If externally applied forces produces along the thickness direction swing piezoelectric patches, then V1 ' and V2 ' equate and anti-phase and cyclic variation.

When piezoelectric patches under the piezoelectric patches polarization effect situation shown in Fig. 4 B, if externally applied forces makes piezoelectric patches produce compression or elongation strain, then V1 '=-V2 '; If it is crooked that externally applied forces produces piezoelectric patches, then V1 ' and V2 ' homophase, i.e. V1 '=V2 '; If externally applied forces vibrates piezoelectric patches along its length, then V1 ' and V2 ' anti-phase and cyclic variation; If externally applied forces makes piezoelectric patches swing along thickness direction, then equal, homophase of V1 ' and V2 ' and cyclic variation.

It will be understood by those skilled in the art that size according to detected V1 ' and V2 ', and V1 ' with the voltage of V2 ' positive and negative or phase place, just can confirm piezoelectric patches stressed situation.When the present embodiment PZT (piezoelectric transducer) uses as transducer; Acoustic pressure to be detected, acceleration force etc. can force piezoelectric patches to produce curved displacement or curved vibration, thereby will produce a pair of differential output signal at the V1 ' and the V2 ' of two signal output part outputs of piezoelectric patches; This can accurately obtain sound wave, acceleration signal through a differential amplifier very easily.Monolithic piezoelectric transducer of the present invention has low-frequency response and higher detection precision preferably, but the accurate sensing function of realizable force, sound, acceleration.

The volume rendering structural representation of the PZT (piezoelectric transducer) that Fig. 6 provides for the embodiment of the invention two; Fig. 7 is the upper surface electrode distribution schematic diagram of PZT (piezoelectric transducer) among Fig. 6; Fig. 8 is the lower surface electrode distribution schematic diagram of PZT (piezoelectric transducer) among Fig. 6.Different with above-mentioned Fig. 1-technical scheme embodiment illustrated in fig. 5 is; In the present embodiment; It is antisymmetry setting at the upper and lower surfaces of piezoelectric patches that the first driving interdigital electrode and second drives interdigital electrode, and accordingly, the first ground connection interdigital electrode and the second ground connection interdigital electrode also are the antisymmetry settings at the upper and lower surfaces of piezoelectric patches; Particularly;As shown in Figure 6, in the present embodiment, the first driving interdigital electrode 21 and the second ground connection interdigital electrode 232 are symmetrical set up and down; Promptly first drive interdigital electrode 21 and the second ground connection interdigital electrode 232 about being provided with in the face of claiming in the piezoelectric patches thickness, and the first ground connection interdigital electrode 231 and the second driving interdigital electrode 22 are arranged in a crossed manner relatively with two the first driving interdigital electrodes 21 and the second ground connection interdigital electrode 232 on the upper and lower surface of piezoelectric patches respectively; The first ground connection interdigital electrode 231 and the second ground connection interdigital electrode 232 form common ground electrode 23 through being electrically connected; Piezoelectric patches 11 drives under the direct voltage effect of interdigital electrode 21, the second driving interdigital electrode 22 and common ground electrode 23 through being applied to first; Form the crossed electrode that is arc line type along piezoelectric patches 11 length directions respectively at the upper surface piezoelectric layer of piezoelectric patches 11 and lower surface piezoelectric layer and divide cloth; Promptly form the cross polarization zone, its polarization effect can be referring to shown in Fig. 4 A or the 4B.

In the present embodiment,, just can produce the polarization distribution effect shown in Fig. 4 A through applying suitable voltage at each electrode; Particularly, like Fig. 6-shown in Figure 8, can drive on the interdigital electrode 21 first and apply voltage V1; On the second driving interdigital electrode 22, apply voltage V2; On common ground electrode 23, apply voltage V3, promptly the first ground connection interdigital electrode 231 and the second ground connection interdigital electrode 232 meet voltage V3 simultaneously, constitute common ground electrode 23 and make V1=-V2; V3=0 carries out respectively and goes up piezoelectric layer and the polarization of lower piezoelectric layer.Like this, between each two adjacent interdigital electrode, will produce the electric polarization distribution that is arc shaped along y direction, shown in Fig. 4 A.

In addition; When applying voltage formation crossed electrode; If the voltage that applies is V1=V2, like this, the arc-shaped electrode direction that forms at the upper and lower surfaces relative position of piezoelectric patches 11 is opposite; Promptly up and down in the piezoelectric layer arc shape electric polarization be to distribute about piezoelectric patches thickness center line C-C ' antisymmetry, thereby can produce the polarization distribution shown in Fig. 4 B.

In the present embodiment, when PZT (piezoelectric transducer) used as piezoelectric actuator, under the polarization effect situation of the piezoelectric patches shown in Fig. 4 A, < 0, piezoelectric patches will extend so as if V1=-V2; If V1=-V2>0, piezoelectric patches will shorten so; If V1 ≠-V2, piezoelectric patches will produce the flexural deformation of thickness direction so.Therefore, if V1 and V2 are the alternating voltage that antiphase and amplitude equate, then piezoelectric patches will produce vibration along its length; If V1 and V2 are synchronous alternating voltage (also pre-bias voltage can be arranged); Then piezoelectric patches will produce the curved vibration along thickness direction; Thus; Through selecting suitable V1 and V2 just can realize piezoelectric patches vibration along the longitudinal direction, or along the flexural vibrations of thickness direction, thereby realize the specific drive function of driver.

In the present embodiment, under the polarization effect situation of the piezoelectric patches shown in Fig. 4 B, < 0, piezoelectric patches will extend so as if V1=V2; If V1=V2>0, piezoelectric patches will shorten so; If V1 ≠ V2, then piezoelectric patches will produce the flexural deformation along thickness direction.Therefore, if during the alternating voltage that V1 and V2 are same-phase and amplitude to be equated, piezoelectric patches will produce along its length and vibrate; If when V1 and V2 were the alternating voltage (also pre-bias voltage can be arranged) of antiphase, piezoelectric patches will produce the flexural vibrations along thickness direction, thereby can realize the bending strain specific drive function of piezoelectric actuator more easily.

In addition; The present embodiment PZT (piezoelectric transducer) is when using as piezoelectric transducer; The one or both ends of piezoelectric patches are fixed, and with common ground electrode 23 ground connection, the first driving interdigital electrode 21 and second drives interdigital electrode 22 and is connected to oscilloscope or potentiometer as signal output part respectively; The other end or middle part at piezoelectric patches apply multi-form and big or small external force; Observe and write down the voltage output that is measured,, just can obtain to be applied to the pressure size information on the piezoelectric patches according to the size of the magnitude of voltage that measures.For ease of explanation, suppose first, to drive the voltage that interdigital electrode 21 places produce be V1 ', second drive the generation of interdigital electrode 22 places voltage be V2 ', the voltage that then produces under like Fig. 4 A or Fig. 4 B situation is explained as follows respectively.

When piezoelectric patches under the piezoelectric patches polarization effect situation shown in Fig. 4 A, if the external force that is applied to the piezoelectric patches other end can make piezoelectric patches produce compression or elongation strain, the voltage V1 ' that then produces=-V2 '; If the external force that is applied on the piezoelectric patches makes piezoelectric patches produce bending, then the voltage V1 ' and the V2 ' of generation will equate, i.e. V1 '=V2 '; If externally applied forces makes piezoelectric patches produce vibration along its length, then equal, anti-phase of V1 ' and V2 ' amplitude and cyclic variation; If externally applied forces produces along the thickness direction swing piezoelectric patches, then equal, homophase of V1 ' and V2 ' amplitude and cyclic variation.

When piezoelectric patches under the piezoelectric patches polarization effect situation shown in Fig. 4 B, if externally applied forces makes piezoelectric patches produce compression or elongation strain, then V1 '=V2 '; If it is crooked that externally applied forces produces piezoelectric patches, then V1 ' and V2 ' anti-phase, promptly V1 '=-V2 '; If externally applied forces vibrates piezoelectric patches along its length, then equal, homophase of V1 ' and V2 ' and cyclic variation; If externally applied forces makes piezoelectric patches swing along thickness direction, then equal, anti-phase of V1 ' and V2 ' and cyclic variation.

The monolithic piezoelectric transducer that the embodiment of the invention provides adopts individual layer piezoelectric patches structure; Through making interdigital electrode on the piezoelectric patches surface; And carry out cross polarization, can make piezoelectric patches be operated in vertical piezoelectric d 33 patterns, traditional relatively twin lamella PZT (piezoelectric transducer) that works in horizontal piezoelectric d 31 patterns;Can have the advantage that displacement is big and energy consumption is little during as driver, can have advantage highly sensitive and that response performance is good during as transducer.The PZT (piezoelectric transducer) that the embodiment of the invention provides is simple in structure, and is easy to make, can effectively reduce cost of manufacture, need not use simultaneously the not material of high-and low-temperature resistance such as organic binder bond in traditional sandwich construction, can work under the environment adverse circumstances such as high low temperature.

The manufacture method schematic flow sheet of the PZT (piezoelectric transducer) that Fig. 9 provides for the embodiment of the invention three.The present embodiment manufacture method can prepare Fig. 1-PZT (piezoelectric transducer) that provides embodiment illustrated in fig. 5, and is as shown in Figure 9 particularly, can may further comprise the steps:

Step 101, be provided with first at the upper surface of piezoelectric patches and drive the interdigital electrode and the first ground connection interdigital electrode, be provided with second at the lower surface of piezoelectric patches and drive the interdigital electrode and the second ground connection interdigital electrode.

Wherein, The first driving interdigital electrode and second drives interdigital electrode and is symmetrical set up and down, and the first ground connection interdigital electrode and the second ground connection interdigital electrode are arranged in a crossed manner relatively with the first driving interdigital electrode and the second driving interdigital electrode respectively at the upper surface and the lower surface of piezoelectric patches.The concrete setting of each interdigital electrode can be repeated no more at this referring to the explanation of the invention described above device embodiment.

Step 102, the first ground connection interdigital electrode and the second ground connection interdigital electrode side electrode through piezoelectric patches is electrically connected, constitutes the common ground electrode.

In this step; One side electrode can be set in the side of piezoelectric patches; Electrode layer all is arranged in whole side that can be as shown in Figure 1, perhaps also can two ground connection interdigital electrodes of upper and lower surfaces are electrically connected be integral through several electrodes is set, and constitutes the common ground electrode.

Step 103, drive interdigital electrode, second first and drive between interdigital electrode and the common ground electrode and apply direct voltage respectively; Upper surface piezoelectric layer and lower surface piezoelectric layer to piezoelectric patches carry out cross polarization, make the upper surface piezoelectric layer of piezoelectric patches and lower surface piezoelectric layer form the cross polarization zone respectively.

In the present embodiment, above-mentioned step 103 also can be accomplished before step 102, and present embodiment is not done special restriction to this.

Before the above-mentioned steps 101, can make mask plate in advance, so that utilize mask plate to make interdigital electrode; Particularly; Can according to the size of the transducer that will make, design template is according to interdigital electrode shape, the size of design; On mask plate, reserve cutting, to be used for printing or sputter interdigital electrode.

In addition, before the above-mentioned steps 101, can obtain the piezoelectric patches of required size, and piezoelectric patches is carried out abrasive disc, ultrasonic cleaning and drying, to guarantee the making precision and the effect of piezoelectric patches from large-area piezoelectric patches cutting.

In the above-mentioned steps 101, the mask plate of making in advance capable of using, at the piezoelectric patches surface sputtering or print interdigital electrode, and the material of electrode can be gold or silver-colored, and after making interdigital electrode, the conduction of detecting electrode is to guarantee to make effect.

In the above-mentioned steps 101, also can drive interdigital electrode and the common ground electrode is provided with contact conductor, so that be electrically connected with other electronic units at each.

In the above-mentioned steps 102, can be through being electrically connected in the mode of side sputter of piezoelectric patches or printed silver electrode or gold electrode two ground connection interdigital electrodes with the piezoelectric patches upper and lower surfaces.

In the above-mentioned steps 103, when piezoelectric patches was polarized, the voltage that is applied on each interdigital electrode can repeat no more at this referring to the explanation of the invention described above device embodiment.

Just can make the PZT (piezoelectric transducer) shown in Fig. 1-Fig. 4 B through above-mentioned steps, it can be used as piezoelectric actuator, converts electrical energy into mechanical energy; Perhaps as transducer; Detect external force, concrete realization can be repeated no more at this referring to the explanation of the invention described above device embodiment.

The manufacture method schematic flow sheet of the PZT (piezoelectric transducer) that Figure 10 provides for the embodiment of the invention four.The present embodiment method can be made and obtained like Fig. 6-PZT (piezoelectric transducer) that provides embodiment illustrated in fig. 8, and shown in figure 10 particularly, the present embodiment method can comprise:

Step 201, be provided with first at the upper surface of piezoelectric patches and drive the interdigital electrode and the first ground connection interdigital electrode; Lower surface at piezoelectric patches is provided with the second driving interdigital electrode and the second ground connection interdigital electrode; Wherein, The first driving interdigital electrode and the second ground connection interdigital electrode are symmetrical set up and down; It is arranged in a crossed manner relatively with the first driving interdigital electrode and the second ground connection interdigital electrode respectively at the upper surface and the lower surface of said piezoelectric patches that the first ground connection interdigital electrode and second drives interdigital electrode, and the first ground connection interdigital electrode and the second ground connection interdigital electrode constitute the common ground electrode;

Step 202, drive interdigital electrode, second first and drive between interdigital electrode and two grounding electrodes and apply direct voltage respectively; Upper surface piezoelectric layer and lower surface piezoelectric layer to piezoelectric patches carry out cross polarization, make the upper surface piezoelectric layer of piezoelectric patches and lower surface piezoelectric layer form the cross polarization zone respectively.

Can find out that different with above-mentioned method shown in Figure 9 is that present embodiment is that the antisymmetry position of the upper and lower surfaces of piezoelectric patches forms the ground connection interdigital electrode respectively and drives interdigital electrode; Thereby can obtain piezoelectric patches shown in Figure 6, it can be used as piezoelectric actuator, converts electrical energy into mechanical energy; Perhaps as transducer; Detect external force, concrete realization can be repeated no more at this referring to the explanation of the invention described above device embodiment.

It will be appreciated by those skilled in the art that; Among each embodiment of the invention described above; The distance that the first driving interdigital electrode, second drives between the interdigital electrode in the interdigital electrode can rationally be set in the practical application as required; With the size of common ground, and the size of piezoelectric patches size, to satisfy the real work needs.

What should explain at last is: above each embodiment is only in order to explaining technical scheme of the present invention, but not to its restriction; Although the present invention has been carried out detailed explanation with reference to aforementioned each embodiment; Those of ordinary skill in the art is to be understood that: it still can be made amendment to the technical scheme that aforementioned each embodiment put down in writing, perhaps to wherein part or all technical characteristic are equal to replacement; And these are revised or replacement, do not make the scope of the essence disengaging various embodiments of the present invention technical scheme of relevant art scheme.

[Claims]

1. a monolithic piezoelectric transducer is characterized in that, comprising:

Piezoelectric patches, the upper surface of said piezoelectric patches and lower surface are respectively arranged with first and drive the interdigital electrode and the second driving interdigital electrode, and the said first driving interdigital electrode and second drives interdigital electrode and is symmetrical set up and down;
The upper surface of said piezoelectric patches and lower surface also are respectively arranged with the first ground connection interdigital electrode and the second ground connection interdigital electrode; The said first ground connection interdigital electrode and the second ground connection interdigital electrode are arranged in a crossed manner relatively with the said first driving interdigital electrode and the second driving interdigital electrode respectively at the upper surface and the lower surface of said piezoelectric patches; And the said first ground connection interdigital electrode and the second ground connection interdigital electrode are electrically connected through the side electrode of said piezoelectric patches, constitute the common ground electrode;
Said piezoelectric patches drives interdigital electrode, second and drives under the direct voltage effect of interdigital electrode and common ground electrode through being applied to said first, forms the cross polarization zone respectively at the upper surface piezoelectric layer and the lower surface piezoelectric layer of said piezoelectric patches.

2. monolithic piezoelectric transducer according to claim 1; It is characterized in that; The voltage that is applied on the said common ground electrode is earthed voltage V3=0, and the voltage that is applied to the said first driving interdigital electrode is V1, and the voltage that is applied to the said second driving interdigital electrode is V2.

3. monolithic piezoelectric transducer according to claim 1 and 2; It is characterized in that; Said monolithic piezoelectric transducer is a piezoelectric actuator; Drive under the driving voltage effect that interdigital electrode and second drives on the interdigital electrode being applied to said first, the upper surface piezoelectric layer through said piezoelectric patches and vertical piezoelectric d 33 patterns of lower surface piezoelectric layer and along the asymmetric strain of the upper surface and the lower surface of y direction make flexural vibrations or the curved displacement of said piezoelectric patches generation along thickness direction.

4. monolithic piezoelectric transducer according to claim 1 and 2 is characterized in that, said monolithic piezoelectric transducer is sonic test transducer, pressure test transducer, vibration-testing transducer or acceleration test transducer.

5. the manufacture method of a monolithic piezoelectric transducer is characterized in that, comprising:
Upper surface at piezoelectric patches is provided with the first driving interdigital electrode and the first ground connection interdigital electrode; Lower surface at said piezoelectric patches is provided with the second driving interdigital electrode and the second ground connection interdigital electrode; Wherein, The said first driving interdigital electrode and second drives interdigital electrode and is symmetrical set up and down, and the said first ground connection interdigital electrode and the second ground connection interdigital electrode are arranged in a crossed manner relatively with the said first driving interdigital electrode and the second driving interdigital electrode respectively at the upper surface and the lower surface of said piezoelectric patches;
The said first ground connection interdigital electrode and the second ground connection interdigital electrode side electrode through said piezoelectric patches is electrically connected, constitutes the common ground electrode;

Drive interdigital electrode, the second driving interdigital electrode and common ground electrode said first and apply direct voltage; Upper surface piezoelectric layer and lower surface piezoelectric layer to said piezoelectric patches carry out cross polarization, make the upper surface piezoelectric layer of said piezoelectric patches and lower surface piezoelectric layer form the cross polarization zone respectively.

6. the manufacture method of monolithic piezoelectric transducer according to claim 5; It is characterized in that; At the upper surface and the lower surface of said piezoelectric patches, make first through sputter or mode of printing respectively and drive interdigital electrode, second driving interdigital electrode, the first ground connection interdigital electrode and the second ground connection interdigital electrode.

7. a monolithic piezoelectric transducer is characterized in that, comprising:
Piezoelectric patches, the upper surface of said piezoelectric patches and lower surface are respectively arranged with first and drive the interdigital electrode and the second ground connection interdigital electrode, and the said first driving interdigital electrode and the second ground connection interdigital electrode are symmetrical set up and down;
The upper surface of said piezoelectric patches and lower surface also are respectively arranged with the first ground connection interdigital electrode and second and drive interdigital electrode; It is arranged in a crossed manner relatively with the said first driving interdigital electrode and the second ground connection interdigital electrode respectively at the upper surface and the lower surface of said piezoelectric patches that the said first ground connection interdigital electrode and second drives interdigital electrode, and said first ground connection interdigital electrode and second ground connection interdigital electrode formation common ground electrode;
Said piezoelectric patches drives interdigital electrode, second and drives under the direct voltage effect of interdigital electrode and common ground electrode through being applied to said first, forms the cross polarization zone respectively at the upper surface piezoelectric layer and the lower surface piezoelectric layer of said piezoelectric patches.

8. the manufacture method of a monolithic piezoelectric transducer is characterized in that, comprising:
Upper surface at piezoelectric patches is provided with the first driving interdigital electrode and the first ground connection interdigital electrode; Lower surface at said piezoelectric patches is provided with the second driving interdigital electrode and the second ground connection interdigital electrode;
Wherein, The said first driving interdigital electrode and the second ground connection interdigital electrode are symmetrical set up and down; It is arranged in a crossed manner relatively with the said first driving interdigital electrode and the second ground connection interdigital electrode respectively at the upper surface and the lower surface of said piezoelectric patches that the said first ground connection interdigital electrode and second drives interdigital electrode, and the said first ground connection interdigital electrode and the second ground connection interdigital electrode constitute the common ground electrode;
Drive interdigital electrode, the second driving interdigital electrode and common ground electrode said first and apply direct voltage; Upper surface piezoelectric layer and lower surface piezoelectric layer to said piezoelectric patches carry out cross polarization, make the upper surface piezoelectric layer of said piezoelectric patches and lower surface piezoelectric layer form the cross polarization zone respectively.