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(54) **ULTRASONIC TRANSDUCER AND METHOD OF MANUFACTURING THE SAME**

(75) Inventors: **Toshiaki Kuniyasu**, Kaisei-machi (JP); **Akinori Harada**, Kaisei-machi (JP); **Takashi Nakamura**, Kaisei-machi (JP)

Correspondence Address:
SUGHRUE MION, PLLC
2100 PENNSYLVANIA AVENUE, N.W.
WASHINGTON, DC 20037 (US)

(73) Assignee: **FUJI PHOTO FILM CO., LTD.**

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(52) **U.S. Cl.** **310/334**

(57) **ABSTRACT**

An ultrasonic transducer in which electrodes can be easily and positively joined to a multiplicity of micro-fabricated vibrators and electric wiring can be easily and positively provided. The ultrasonic transducer has a vibrator arrangement having a plurality of vibrators, each formed with first and second electrodes, provided in a predetermined arrangement; an interlayer board for holding the vibrator arrangement in which a plurality of through holes are respectively formed in positions corresponding to the second electrodes of the vibrators; and a wiring board formed with a plurality of electrodes electrically connected to the second electrodes of the vibrators through the through holes of the interlayer board, respectively.

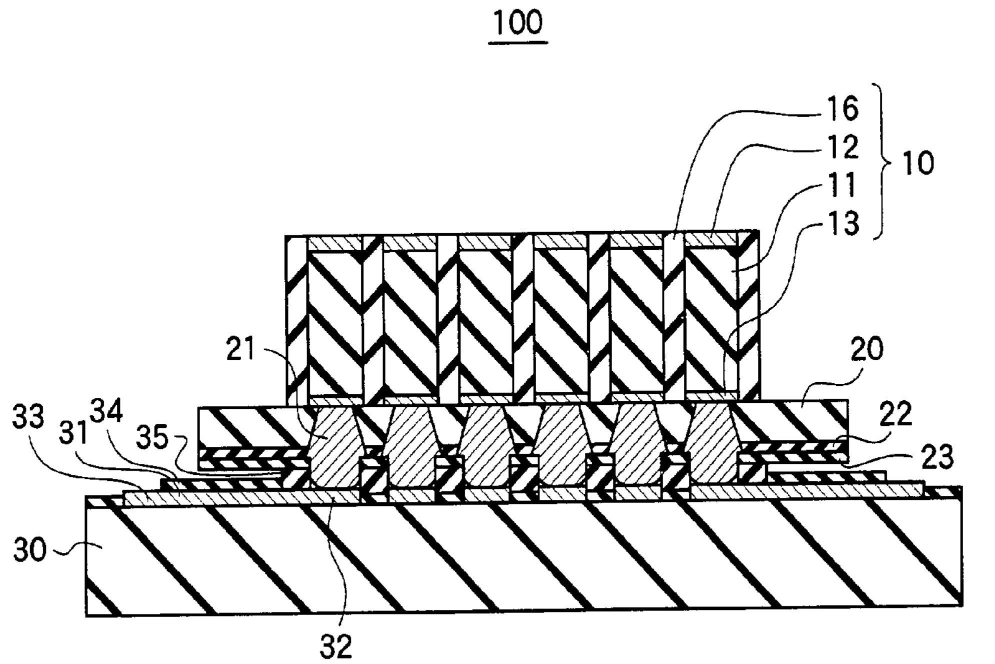


FIG.1

100

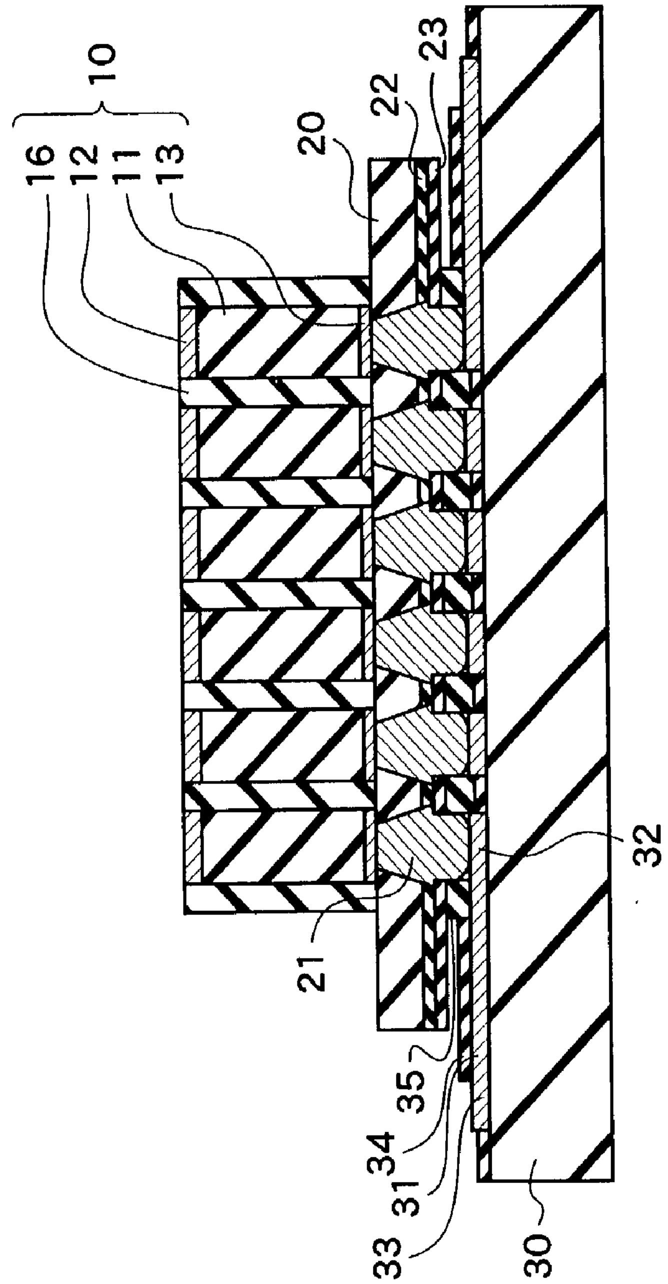


FIG.2

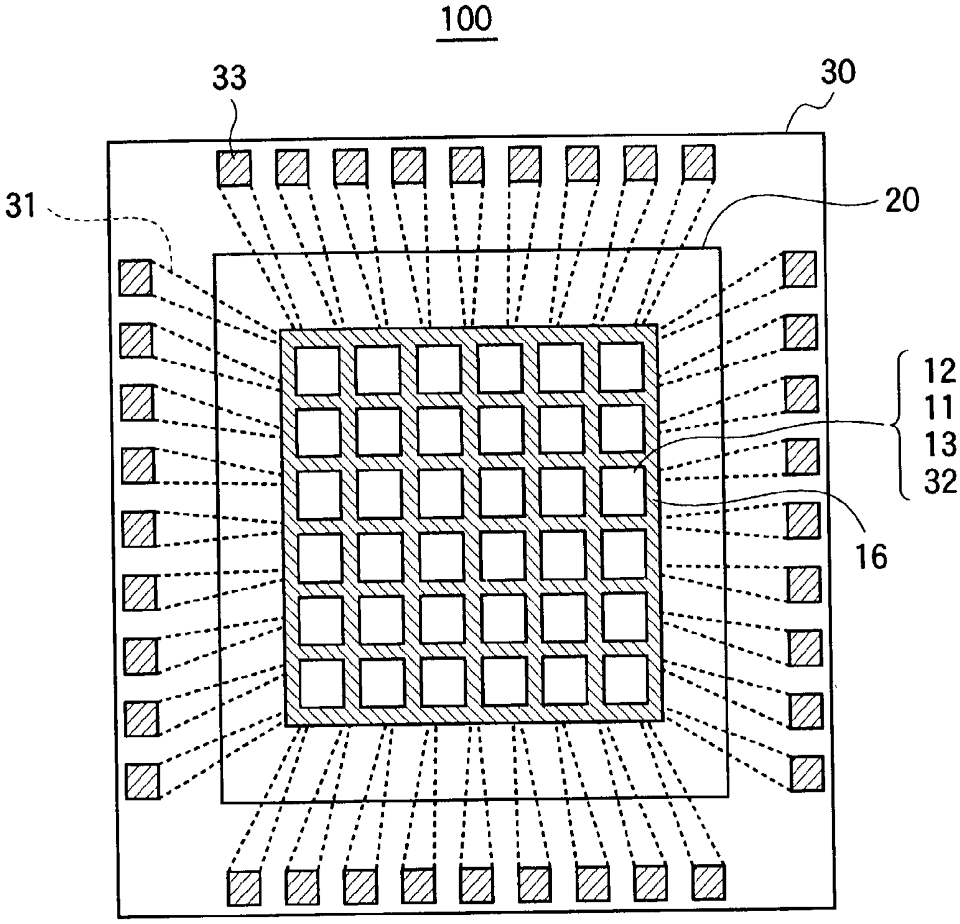


FIG.3

100

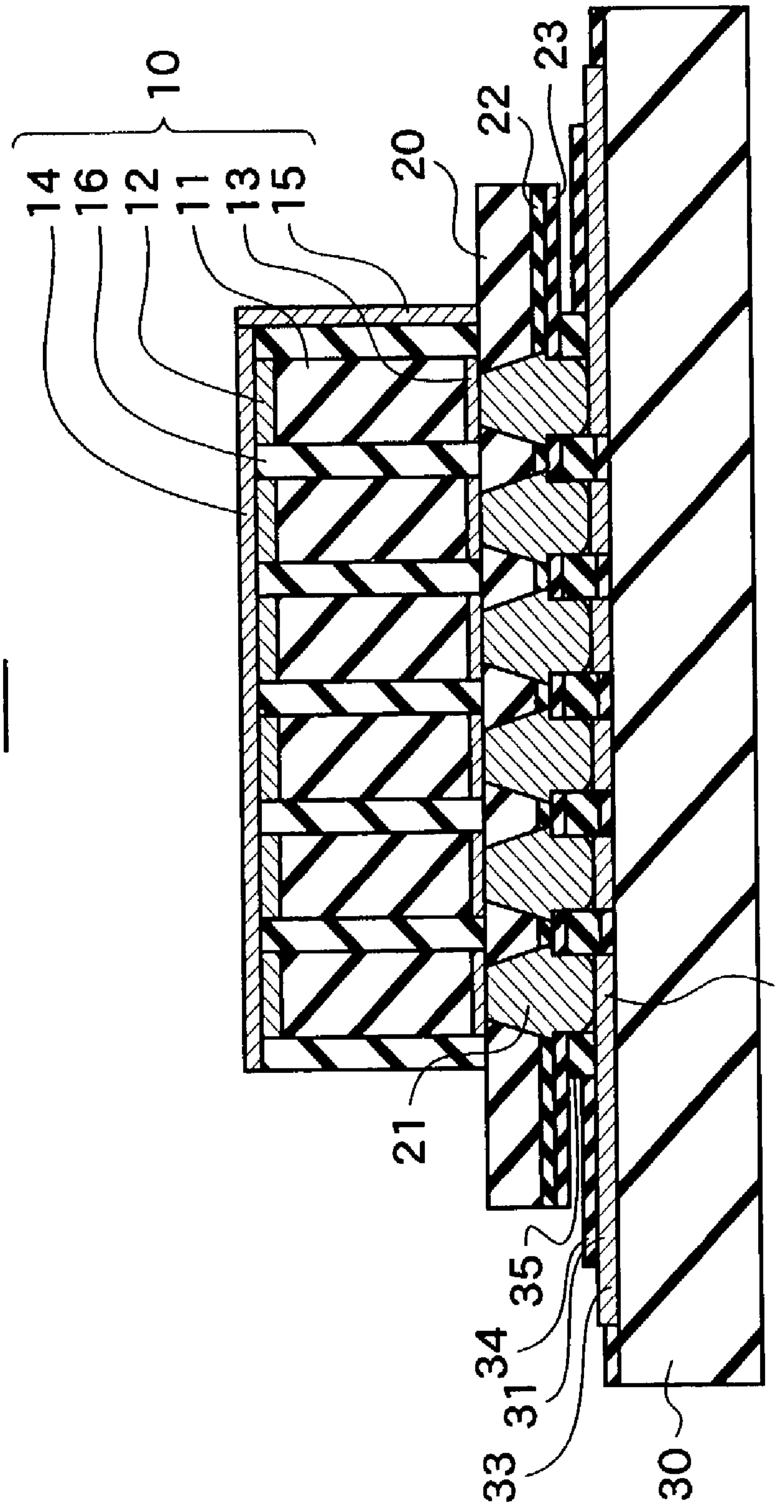


FIG.4

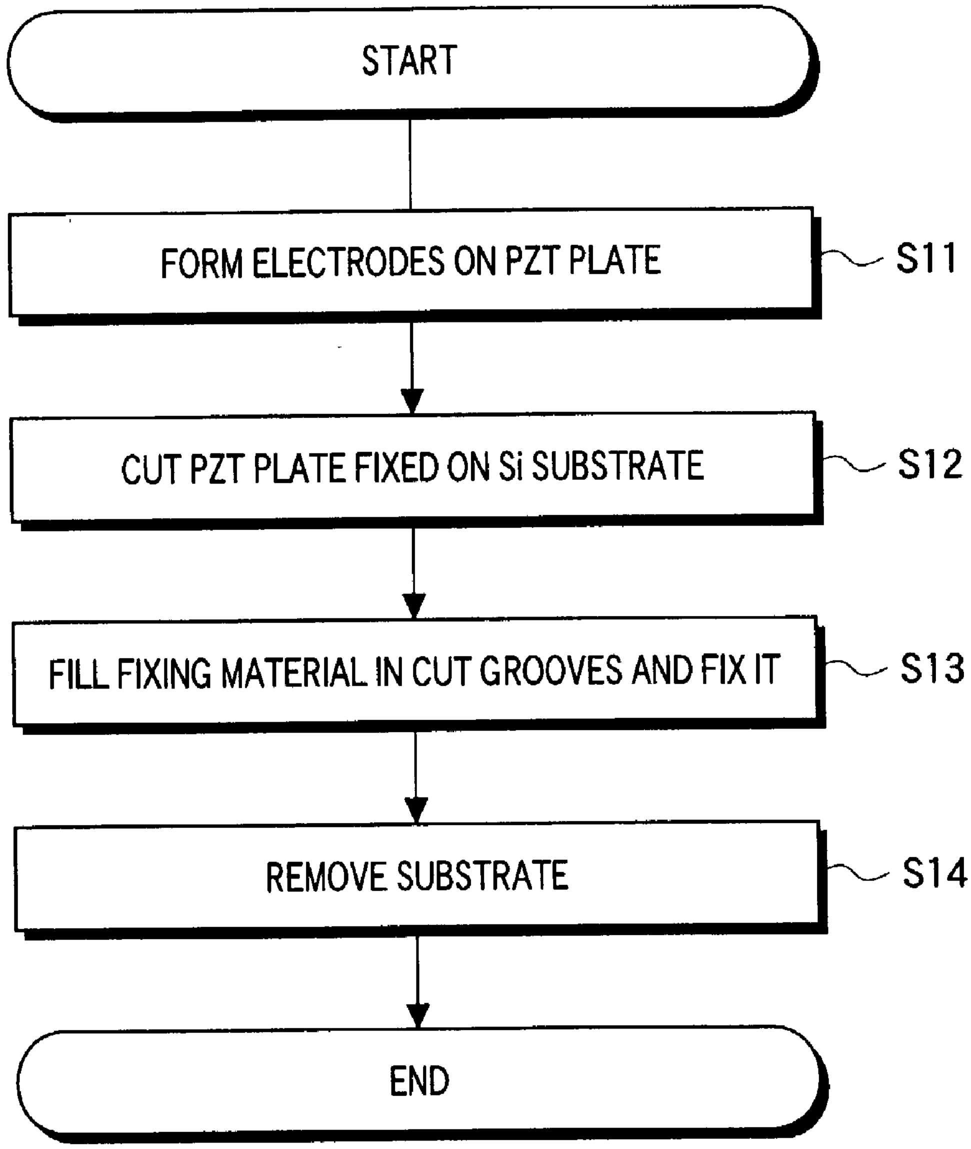

START
FORM ELECTRODES ON PZT PLATE
S11
CUT PZT PLATE FIXED ON Si SUBSTRATE
S12
FILL FIXING MATERIAL IN CUT GROOVES AND FIX IT
S13
REMOVE SUBSTRATE
S14
END

FIG.5A

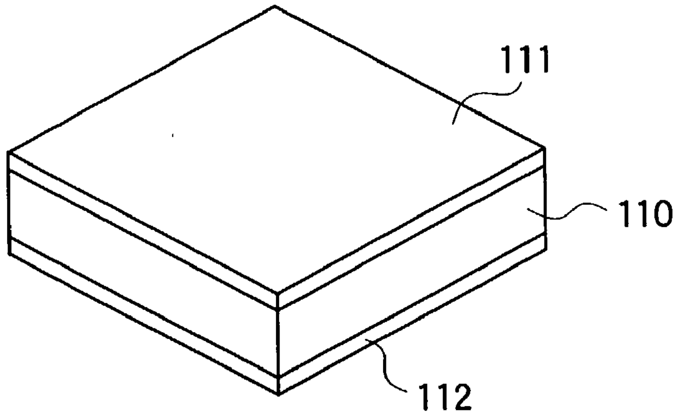


FIG.5B

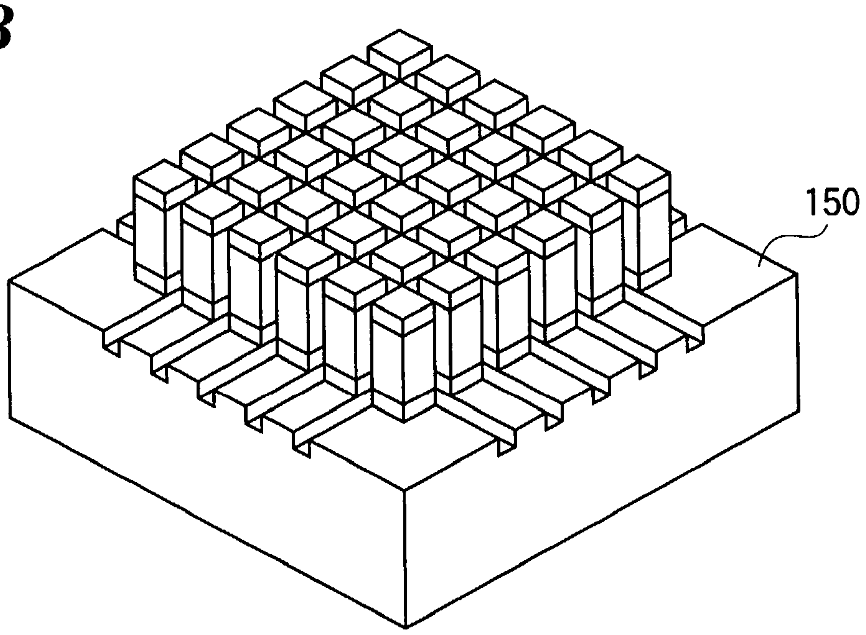


FIG.5C

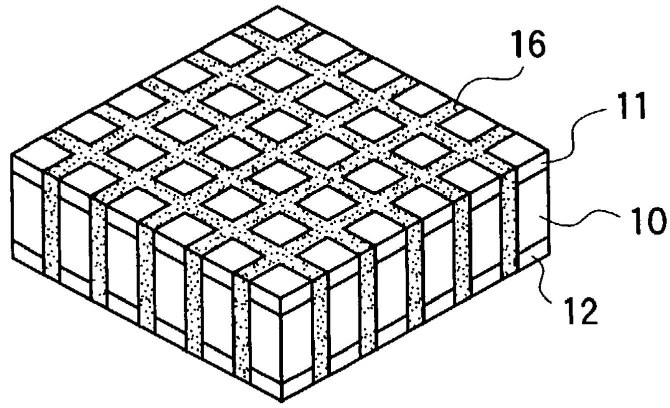


FIG.6

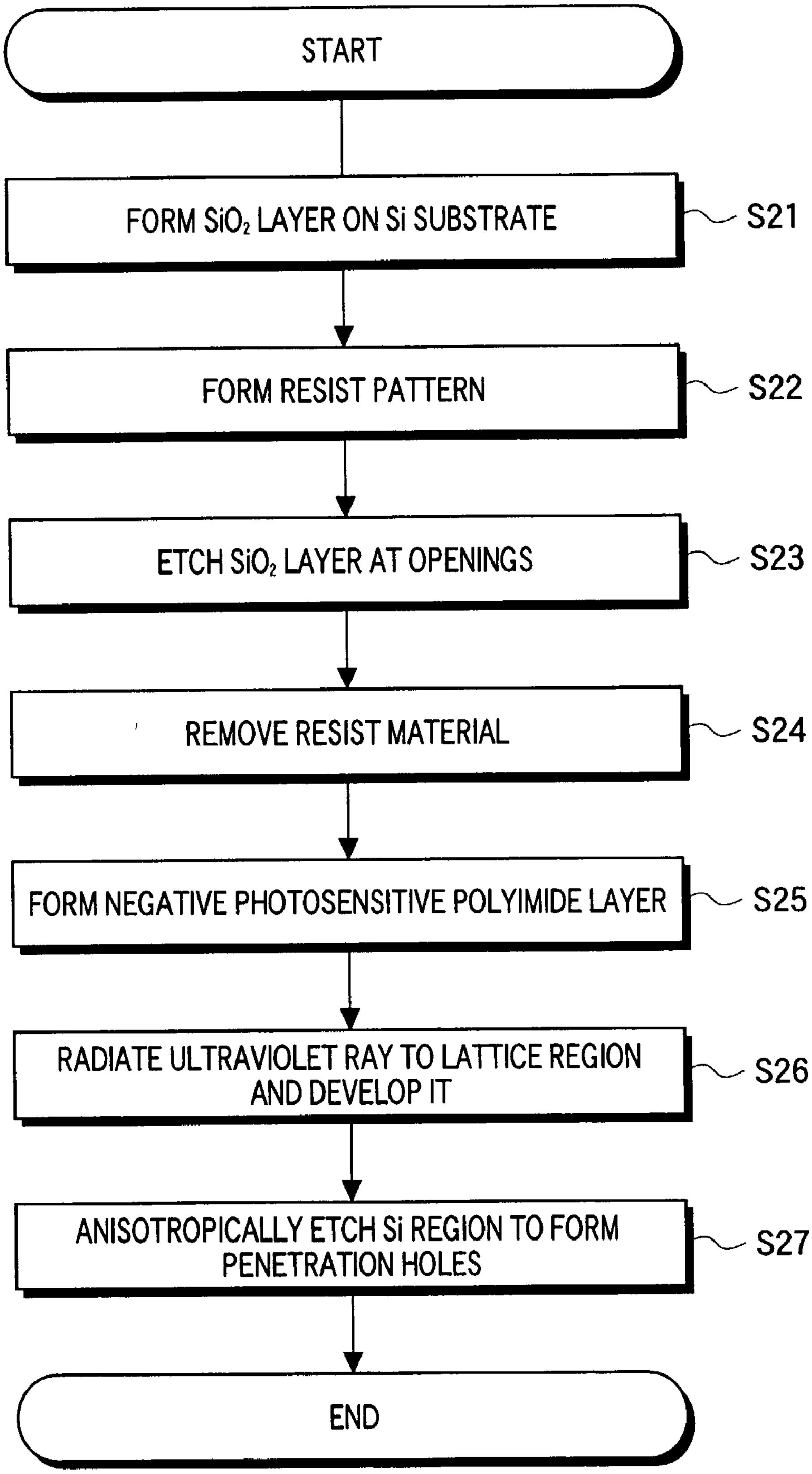

START
FORM SiO_2 LAYER ON Si SUBSTRATE
S21
FORM RESIST PATTERN
S22
ETCH SiO_2 LAYER AT OPENINGS
S23
REMOVE RESIST MATERIAL
S24
FORM NEGATIVE PHOTOSENSITIVE POLYIMIDE LAYER
S25
RADIATE ULTRAVIOLET RAY TO LATTICE REGION AND DEVELOP IT
S26
ANISOTROPICALLY ETCH Si REGION TO FORM PENETRATION HOLES
S27
END

FIG.7A

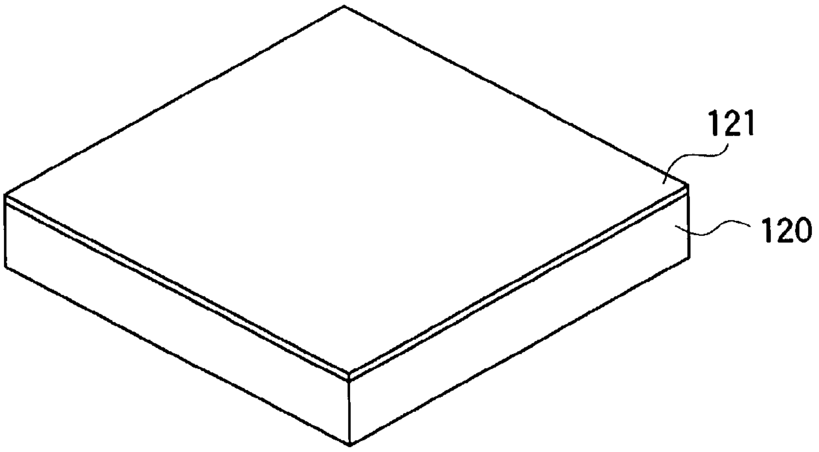


FIG.7B

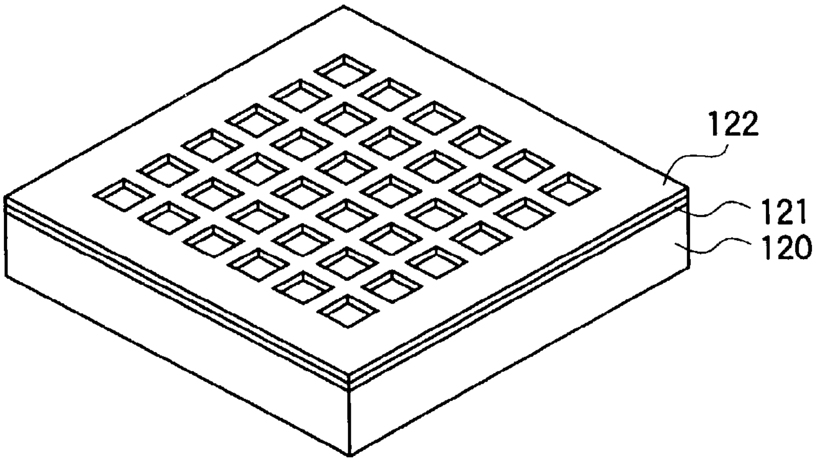


FIG.7C

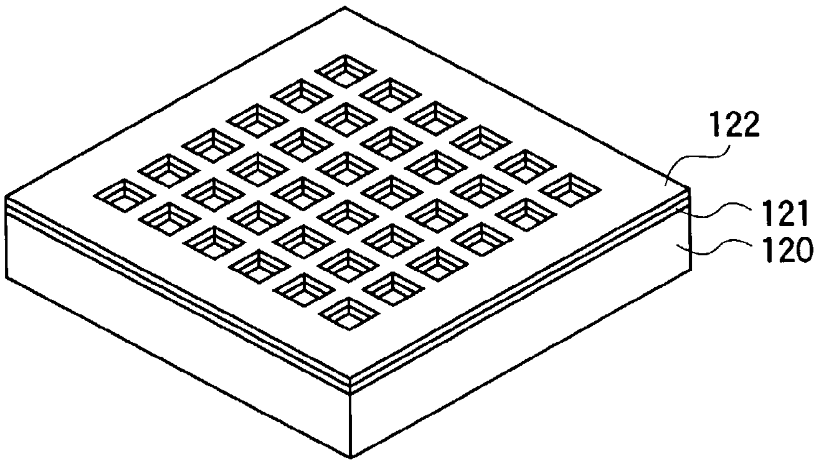


FIG.8A

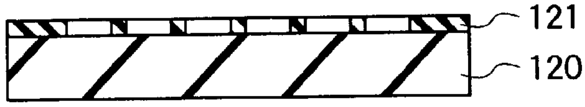


FIG.8B

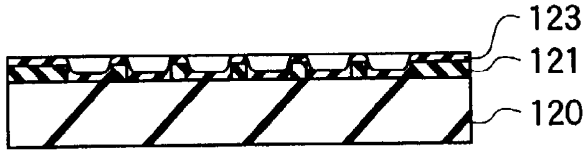


FIG.8C

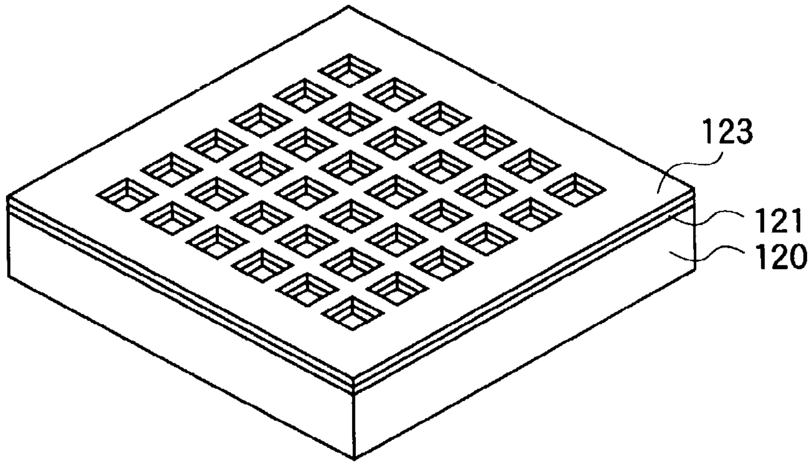


FIG.8D

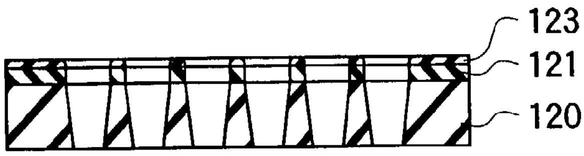


FIG.9

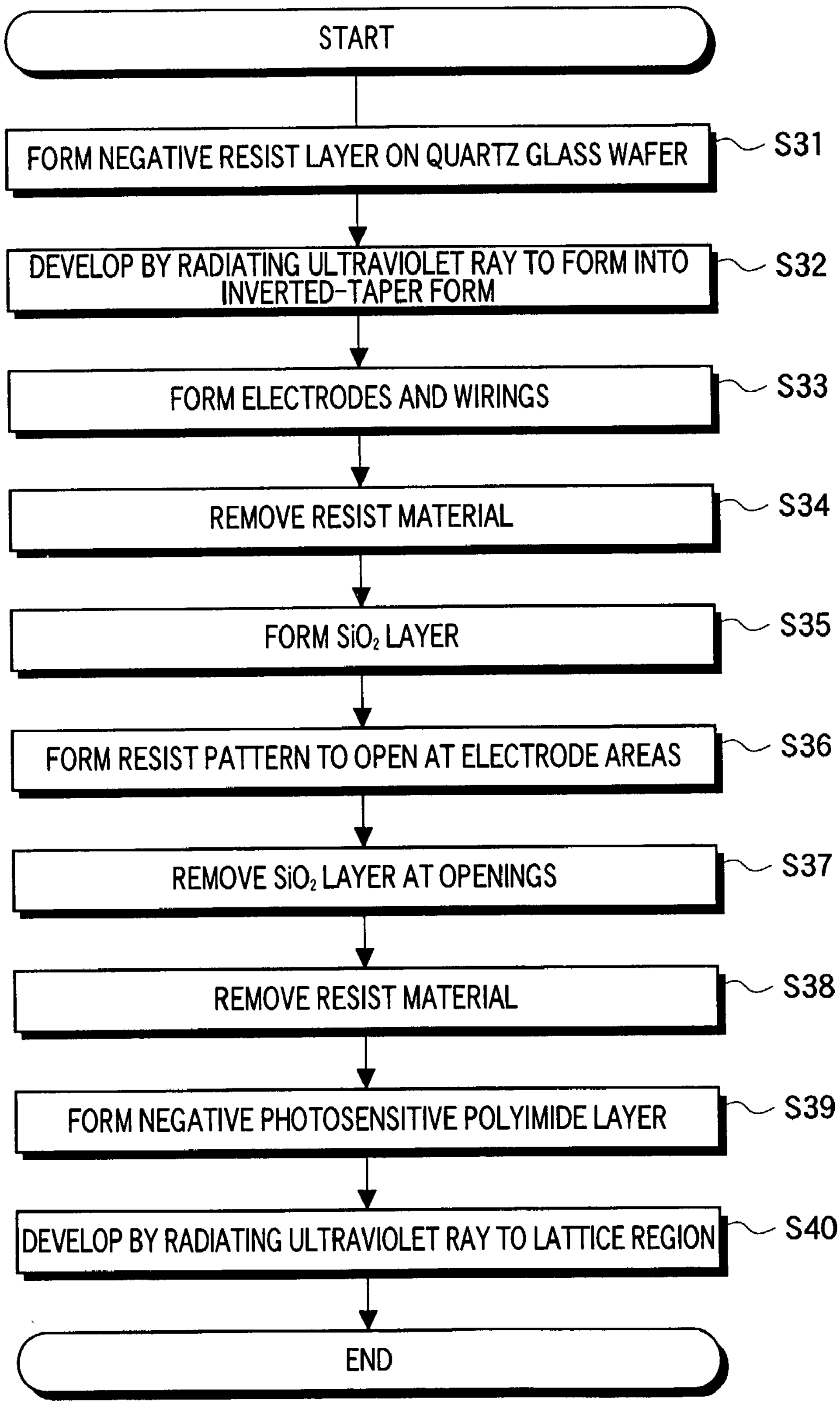

START
FORM NEGATIVE RESIST LAYER ON QUARTZ GLASS WAFER
S31
DEVELOP BY RADIATING ULTRAVIOLET RAY TO FORM INTO INVERTED-TAPER FORM
S32
FORM ELECTRODES AND WIRINGS
S33
REMOVE RESIST MATERIAL
S34
FORM SiO_2 LAYER
S35
FORM RESIST PATTERN TO OPEN AT ELECTRODE AREAS
S36
REMOVE SiO_2 LAYER AT OPENINGS
S37
REMOVE RESIST MATERIAL
S38
FORM NEGATIVE PHOTOSENSITIVE POLYIMIDE LAYER
S39
DEVELOP BY RADIATING ULTRAVIOLET RAY TO LATTICE REGION
S40
END

FIG.10A

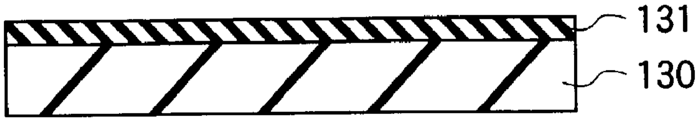


FIG.10B

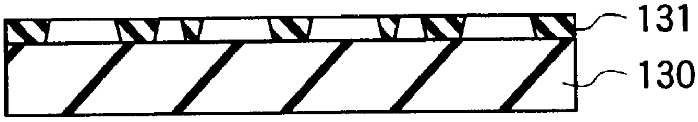


FIG.10C

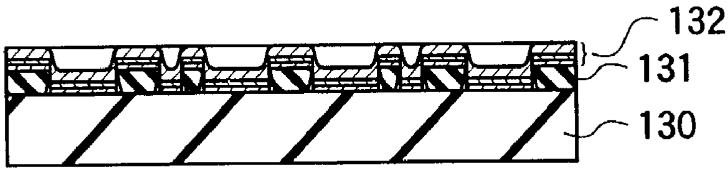


FIG.10D

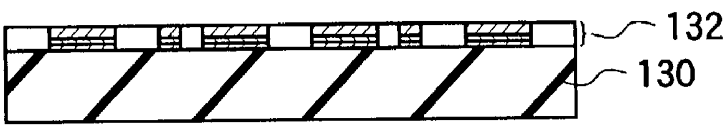


FIG.10E

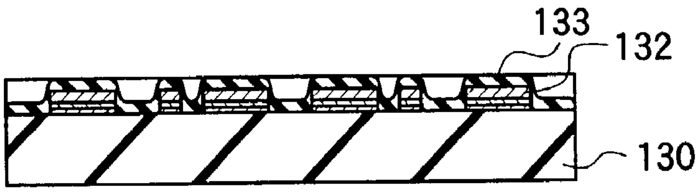


FIG.10F

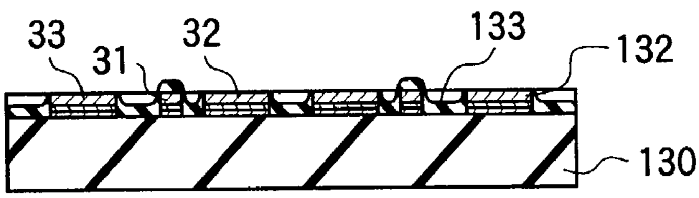


FIG.10G

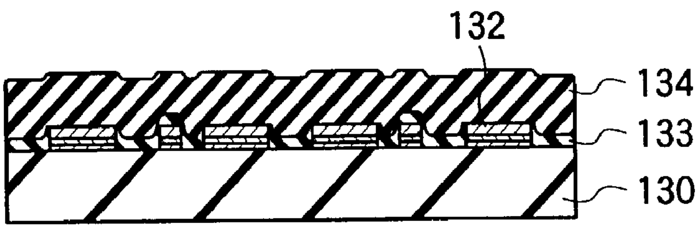


FIG.10H

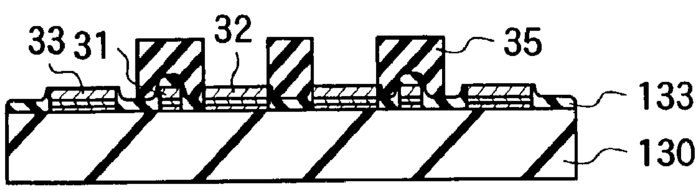


FIG.11A

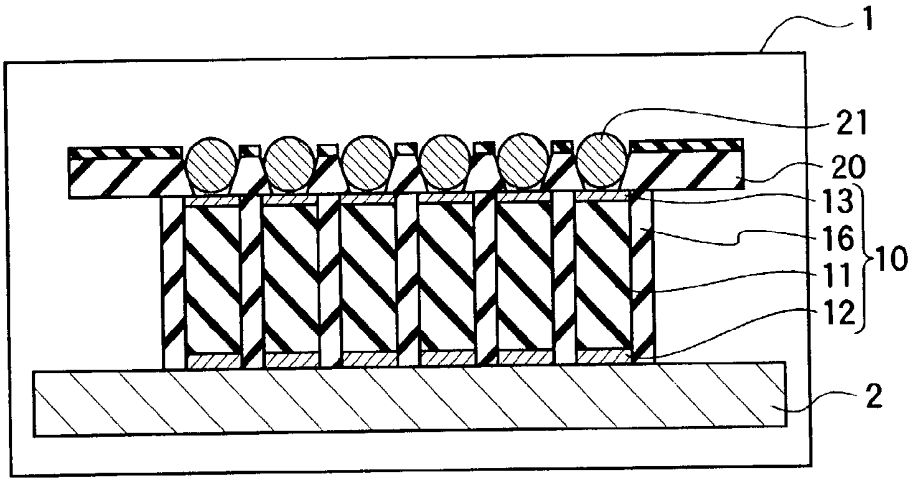


FIG.11B

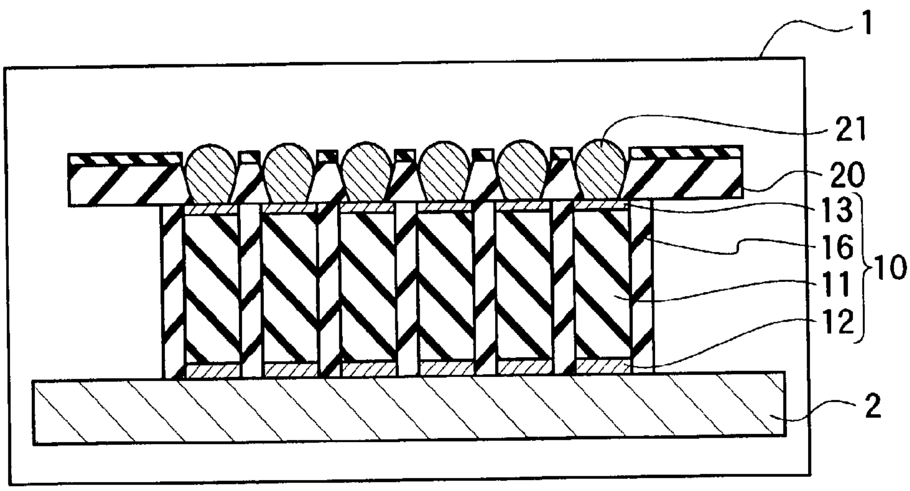


FIG.12A

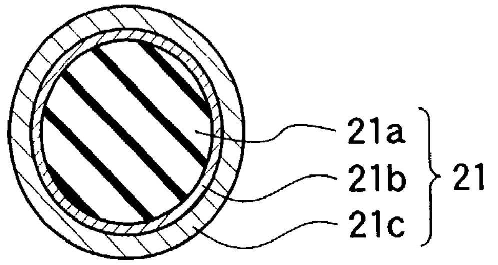


FIG.12B

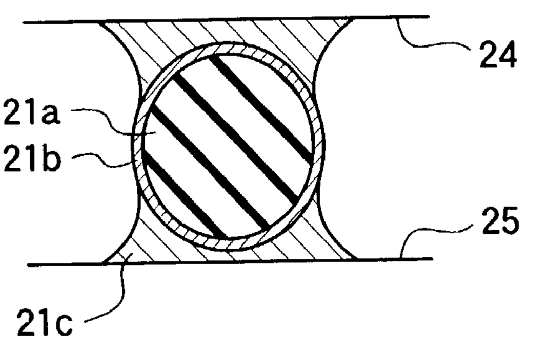


FIG.12C

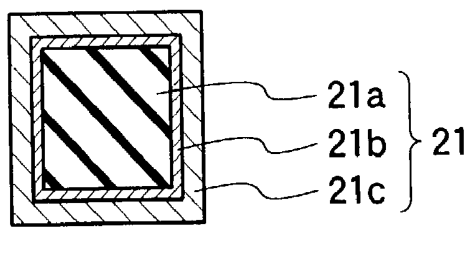


FIG.12D

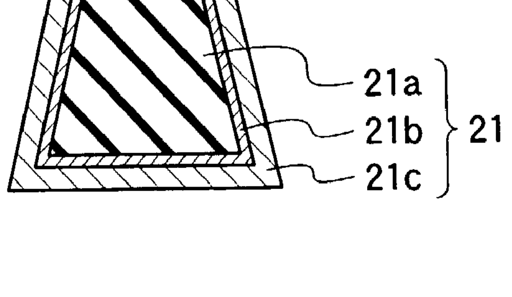


FIG.13

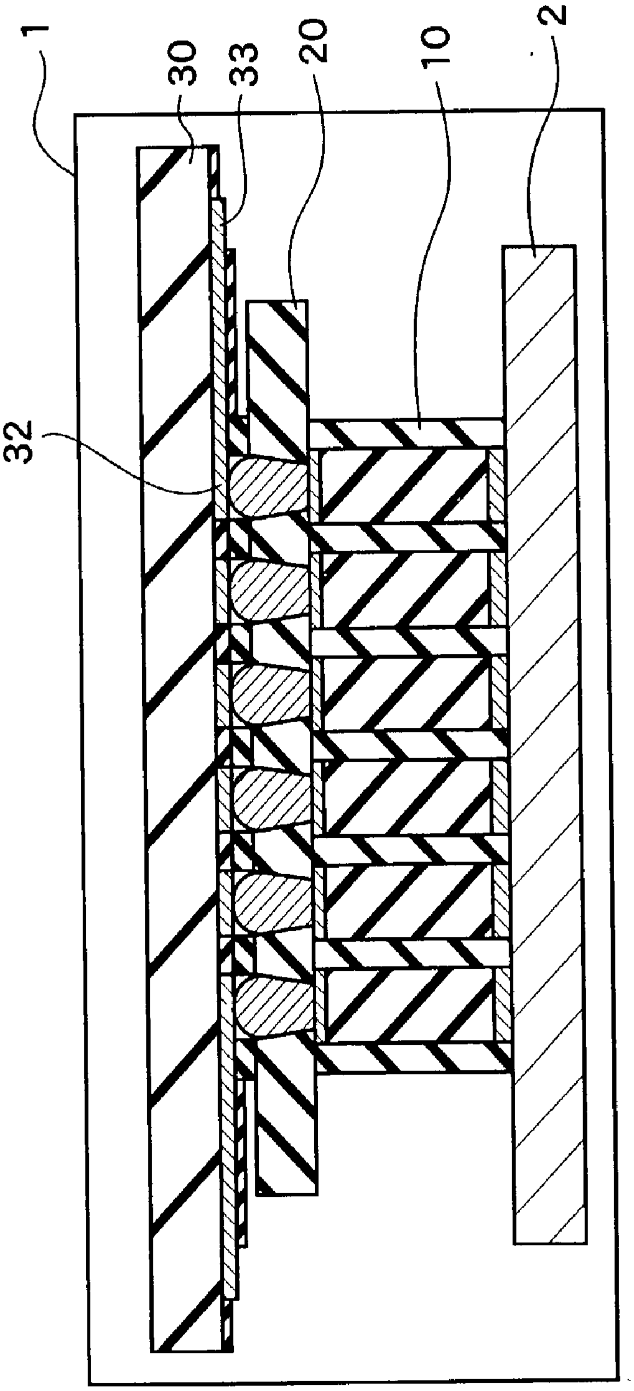


FIG.14

200

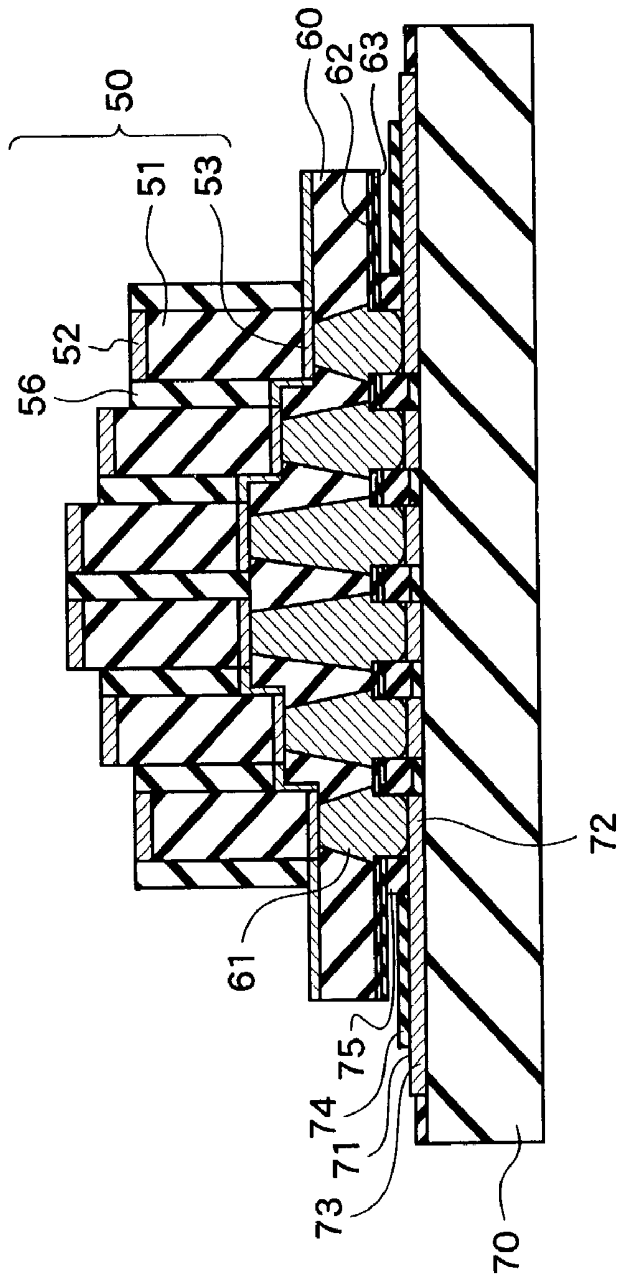


FIG.15

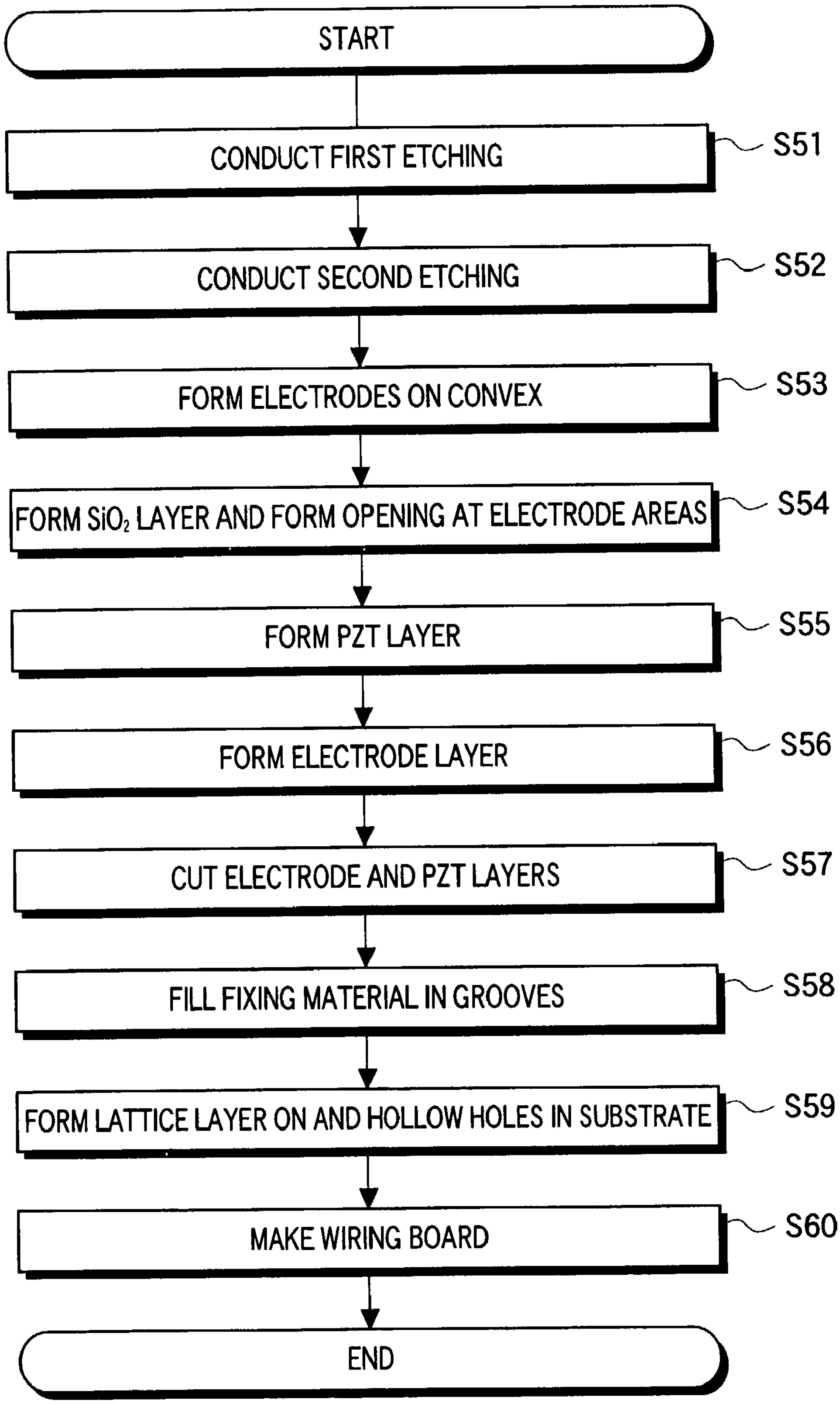

START
CONDUCT FIRST ETCHING
S51
CONDUCT SECOND ETCHING
S52
FORM ELECTRODES ON CONVEX
S53
FORM SiO2 LAYER AND FORM OPENING AT ELECTRODE AREAS
S54
FORM PZT LAYER
S55
FORM ELECTRODE LAYER
S56
CUT ELECTRODE AND PZT LAYERS
S57
FILL FIXING MATERIAL IN GROOVES
S58
FORM LATTICE LAYER ON AND HOLLOW HOLES IN SUBSTRATE
S59
MAKE WIRING BOARD
S60
END

FIG.16A

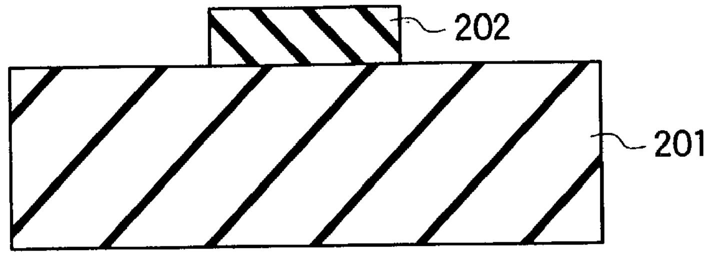


FIG.16B

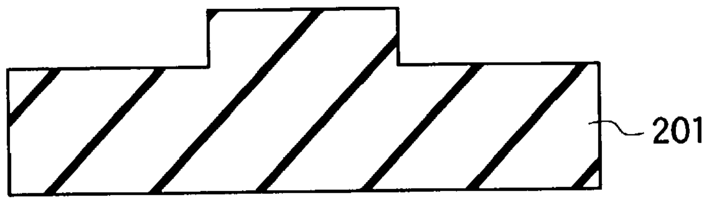


FIG.16C

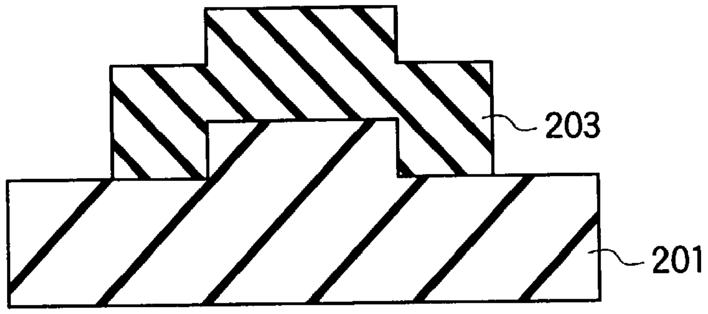


FIG.16D

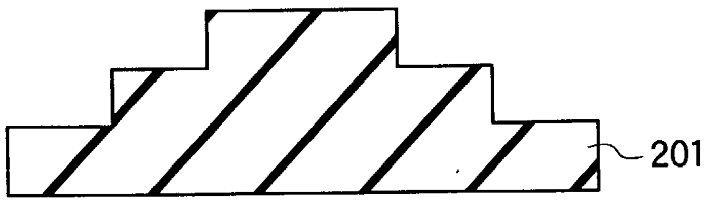


FIG.17A

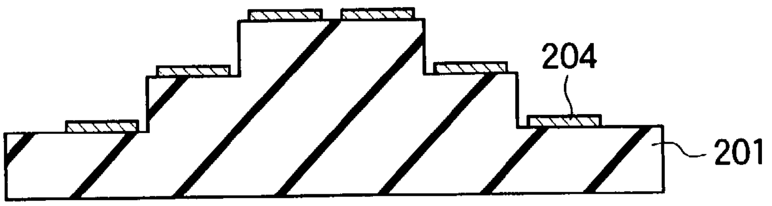


FIG.17B

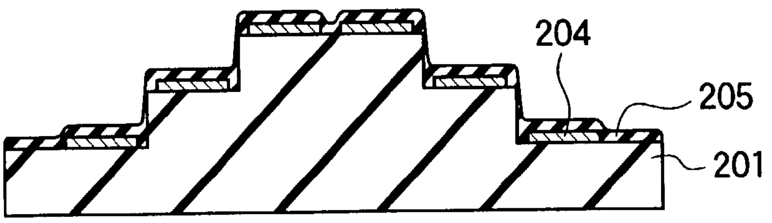


FIG.17C

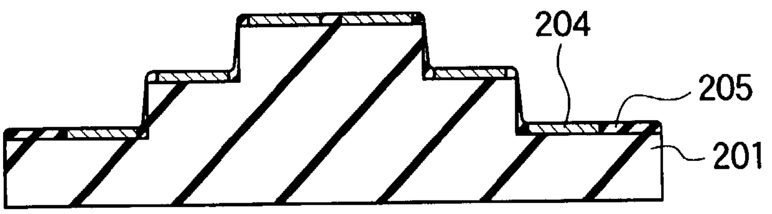


FIG.17D

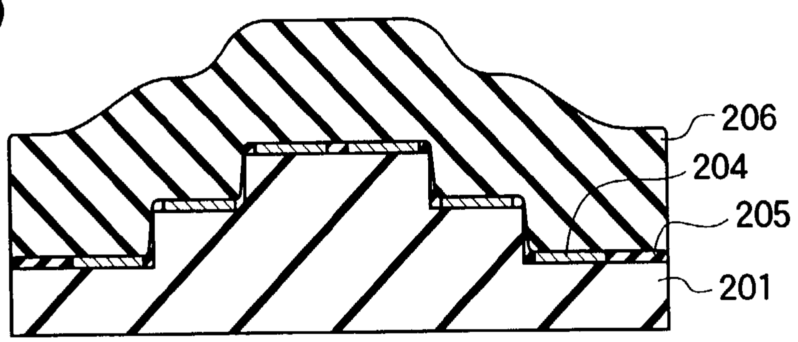


FIG.17E

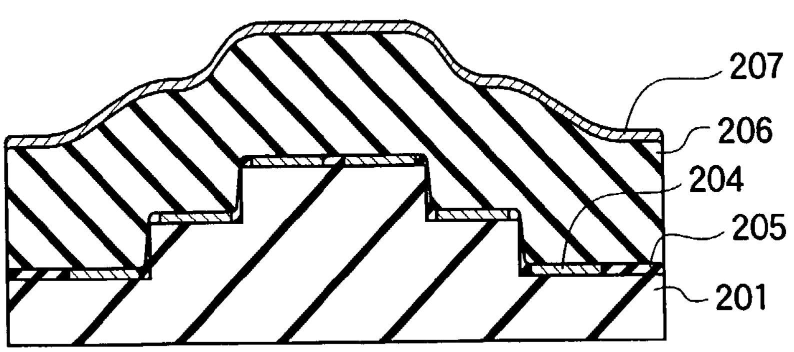


FIG.18A

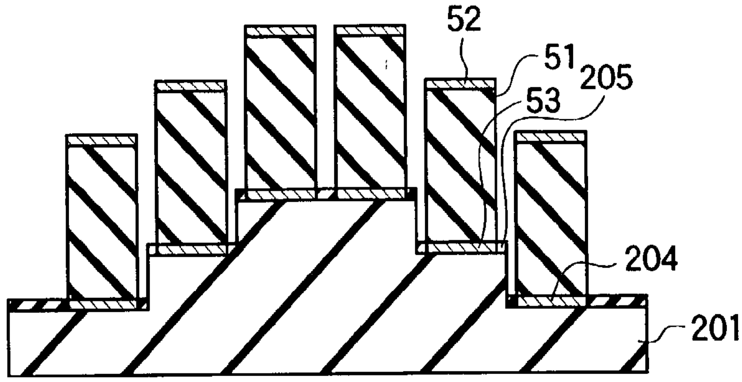


FIG.18B

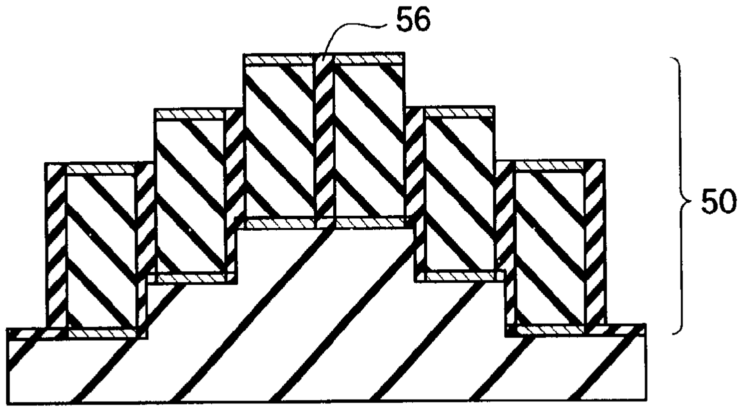


FIG.18C

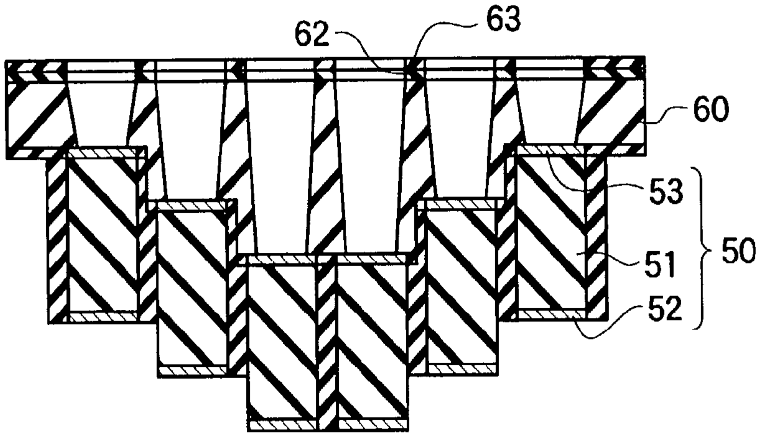


FIG.19A

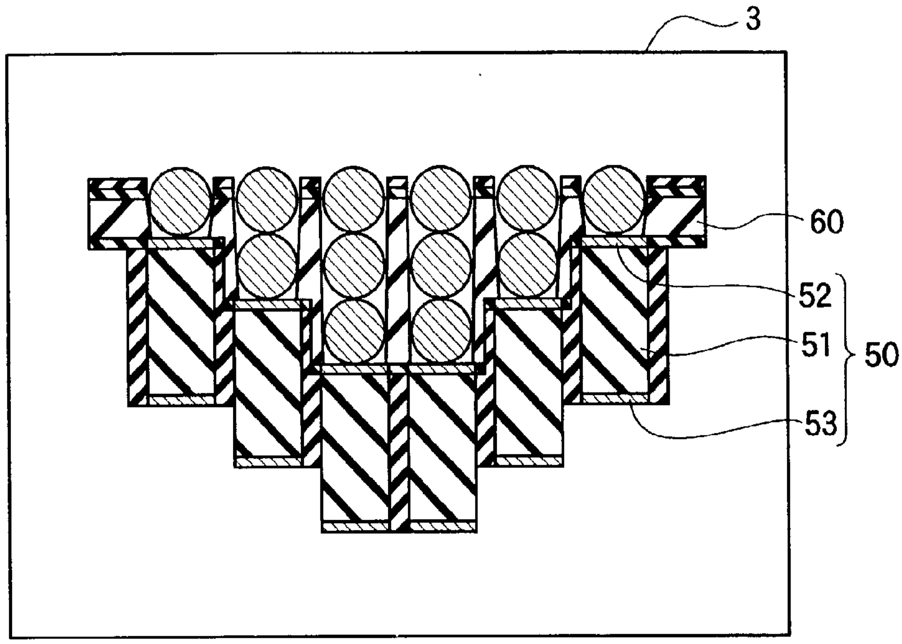
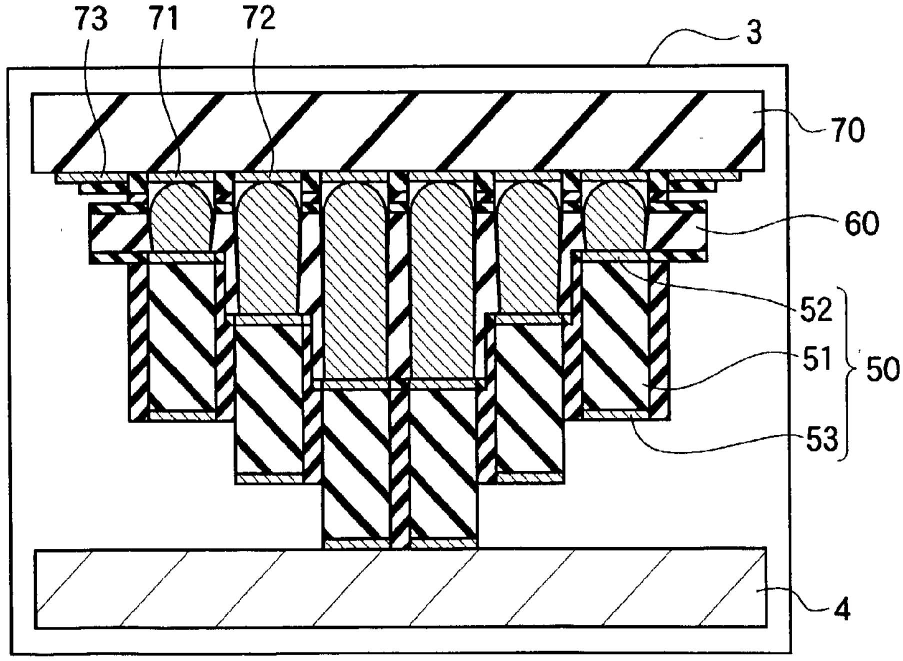


FIG.19B



ULTRASONIC TRANSDUCER AND METHOD OF MANUFACTURING THE SAME

BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention

[0002] The present invention relates to an ultrasonic transducer for use in ultrasonic diagnostic medicine and, more particularly, to an ultrasonic transducer including a two-dimensional sensor array. The present invention also relates to a method of manufacturing such an ultrasonic transducer.

[0003] 2. Description of a Related Art

[0004] In the ultrasonic diagnostic apparatus, it has conventionally been general to use, as the ultrasonic transducer for ultrasonic-wave transmission and reception, a one-dimensional sensor array having piezoelectric elements (piezoelectric vibrators) such as piezoelectric ceramics represented by PZT (Pb (lead) zirconate titanate) or polymer piezoelectric elements represented by PVDF (polyvinyl difluoride). Furthermore, by mechanically moving such a one-dimensional sensor array, a two-dimensional image is acquired whereby a three-dimensional image is obtained by combining a plurality of two-dimensional images together.

[0005] In this approach, however, there is time lag in respect of a moving direction of the one-dimensional sensor array. Because of combining together the sectional images different in time, the resultant image will be an obscured one. Accordingly, this is not suited for an object to be inspected such as a living body as in carrying out ultrasonic-echo observations in ultrasonic diagnostic medicine.

[0006] For this reason, there is a recent attempt to use a two-dimensional sensor array having ultrasonic-wave transmitting/receiving elements arranged in two dimensions to electrically scan an object to be inspected with an ultrasonic wave wherein a technique of dynamic focusing or the like is used in a depth direction, thereby improving the quality of an ultrasonic image. Namely, by using a two-dimensional sensor array, a two-dimensional image can be acquired without mechanically moving the sensor array, which makes possible to obtain a high quality three-dimensional image.

[0007] On the other hand, in order to place a probe having a two-dimensional sensor array into practical application, there is a need to densely integrate a multiplicity of elements for transmitting and receiving ultrasonic waves. Particularly, in the case of using piezoelectric vibrators of the above-mentioned PZT or PVDF as ultrasonic-wave transmitting/receiving elements, there is a necessity of micro-fabricating the elements and wiring to a multiplicity of elements. However, there is difficulty in miniaturizing and integrating elements to an extent beyond that in the present situation. An approach to resolve them is now under consideration.

[0008] For example, JP-A-8-186896 discloses an ultrasonic transducer capable of eliminating the electric, acoustic leak between piezoelectric vibrators to improve the characteristic of an emission ultrasonic wave, and method of manufacturing the same. According to the document, the ultrasonic transducer has a plurality of piezoelectric vibrators in two-dimensional arrangement formed by completely cutting a piezoelectric plate for ultrasonic-wave emission, a plurality of drive electrodes each formed on a surface opposed to an ultrasonic-wave emitting surface of the piezoelectric vibrator, a common electrode formed on the ultrasonic-wave emitting surface of the piezoelectric vibrator, and a printed wiring board electrically connected to each of the drive electrodes to supply an externally applied voltage to the drive electrodes.

[0009] However, according to the scheme of directly joining together the piezoelectric vibrators and the solder material joined on a copper wiring arranged in the printed wiring board, the number of wiring pieces per unit area increases with increase in the number of piezoelectric vibrators, which requires to miniaturize the copper wiring in its extended portion arranged in the printed wiring board. Due to this, the adjacent ones of solder are apt to contact by the spread of solder, which causes lower in yield or reliability. Further, this scheme causes deviation in joining the solder material to the piezoelectric-vibrator electrodes, which makes it difficult to provide positive contacts. Furthermore, in this scheme, there is encountered a limitation in the number of wiring pieces. Meanwhile, in the case the printed wiring board uses a flexible wiring board such as a polyimide film, the polyimide film readily shrink due to heat, and therefore, it causes a problem that the adjacent ones of solder is put into contact by the shrinkage of the polyimide film.

[0010] In order to realize an ultrasonic transducer capable of obtaining a high-resolution ultrasonic image with reproducibility, there is a need to easily and positively carry out joining a multiplicity of precise vibrators to electrodes as well as providing electrical wiring. For this reason, there is a desire to develop a novel method of joining vibrators to electrodes, a novel method of providing wiring, and so on.

SUMMARY OF THE INVENTION

[0011] The present invention has been made in view of the foregoing problem. It is an object of the present invention to provide an ultrasonic transducer in which electrodes can be easily and positively joined to a multiplicity of micro-fabricated vibrators and electric wiring can be easily and positively provided.

[0012] In order to solve the above problem, an ultrasonic transducer according to the present invention comprises: a vibrator arrangement having a plurality of vibrators, each formed with first and second electrodes, provided in a predetermined arrangement; a first board for holding the vibrator arrangement, said first board being formed with a plurality of through holes in positions corresponding to the second electrodes of the vibrators; and a second board formed with a plurality of electrodes electrically connected to the second electrodes of the plurality of vibrators through the plurality of through holes of the first board, respectively.

[0013] Meanwhile, a method of manufacturing an ultrasonic transducer according to the present invention comprises the steps of: (a) preparing a first board formed with a plurality of through holes in predetermined positions; (b) arranging a plurality of vibrators, each formed with first and second electrodes, onto a first surface of the first board; (c) arranging a second board, formed with a plurality of electrodes, onto a second surface of the first board; and (d) arranging solder in the plurality of through holes formed in the first board and respectively joining the second electrodes of the plurality of vibrators to the plurality of electrodes of the second board through the plurality of through holes formed in the first board by using the solder.

[0014] According to the invention, the electrodes formed on the vibrators and the electrodes formed on the second board are joined together by using the solder filled in the through holes formed in the first board. It is, therefore, possible to easily and positively join the electrodes to the multiplicity of micro-fabricated vibrators and providing the electric wiring.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] **FIG. 1** is a sectional view showing an ultrasonic transducer according to a first embodiment of the present invention;

[0016] **FIG. 2** is a plan view showing the ultrasonic transducer according to the first embodiment of the invention;

[0017] **FIG. 3** is a view showing a modification to the ultrasonic transducer of **FIG. 1**;

[0018] **FIG. 4** is a flowchart showing a fabrication process of a vibrator arrangement in a method of manufacturing an ultrasonic transducer according to the first embodiment of the invention;

[0019] FIGS. **5**A-**5**C are views for explaining a fabrication process of a vibrator arrangement in the method of manufacturing an ultrasonic transducer according to the first embodiment of the invention;

[0020] **FIG. 6** is a flowchart showing a fabrication process of an interlayer board in the method of manufacturing an ultrasonic transducer according to the first embodiment of the invention;

[0021] FIGS. **7**A-**7**C are views for explaining a fabrication process of an interlayer board in the method of manufacturing an ultrasonic transducer according to the first embodiment of the invention;

[0022] FIGS. **8**A-**8**D are views for explaining a fabrication process of an interlayer board in the method of manufacturing an ultrasonic transducer according to the first embodiment of the invention;

[0023] **FIG. 9** is a flowchart showing a fabrication process of a wiring board in the method of manufacturing an ultrasonic transducer according to the first embodiment of the invention;

[0024] FIGS. **10**A-**10**H are views for explaining a fabrication process of a wiring board in the method of manufacturing an ultrasonic transducer according to the first embodiment of the invention;

[0025] **FIGS. 11A and 11B** are views for explaining a process of joining together the vibrator arrangement and the interlayer board in the method of manufacturing an ultrasonic transducer according to the first embodiment of the invention;

[0026] FIGS. **12A**-**12D** are sectional views showing a resin-contained solder;

[0027] **FIG. 13** is a view for explaining a process of joining together the interlayer board and the wiring board in the method of manufacturing an ultrasonic transducer according to the first embodiment of the invention;

[0028] **FIG. 14** is a sectional view showing an ultrasonic transducer according to a second embodiment of the invention;

[0029] **FIG. 15** is a flowchart showing a method of manufacturing an ultrasonic transducer according to a second embodiment of the invention;

[0030] FIGS. **16**A-**16**D are views for explaining a fabrication process of an interlayer board having steps in the method of manufacturing an ultrasonic transducer according to the second embodiment of the invention;

[0031] FIGS. **17**A-**17**E are views for explaining a fabrication process of a vibrator arrangement having steps in the method of manufacturing an ultrasonic transducer according to the second embodiment of the invention;

[0032] FIGS. **18**A-**18**C are views for explaining a fabrication process of an interlayer board formed with a vibrator arrangement in the method of manufacturing an ultrasonic transducer according to the second embodiment of the invention; and

[0033] **FIGS. 19A and 19B** are views for explaining a process of joining together the interlayer board and the wiring board in the method of manufacturing an ultrasonic transducer according to the second embodiment of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0034] Embodiments of the present invention will now be explained with reference to the drawings. Note that the same constituent elements are attached with the same reference numerals and explanation thereof will be omitted.

[0035] **FIG. 1** is a sectional view showing an ultrasonic transducer according to a first embodiment of the present invention. Meanwhile, **FIG. 2** is a plan view of the ultrasonic transducer as shown in **FIG. 1**.

[0036] As shown in **FIG. 1**, an ultrasonic transducer **100** includes a vibrator arrangement having a plurality of vibrators (hereinafter, merely referred also to as "elements") placed in two-dimensional arrangement to transmit and receive ultrasonic waves. Although the vibrator arrangement for use in actual ultrasonic diagnosis includes a multiplicity of elements in the number, for example, of 60×60 or more (several thousands to several tens of thousands), this embodiment explains with the number of elements of 6×6 for simplicity sake. In the ultrasonic transducer **100**, there are used as the vibrators piezoelectric elements of piezoelectric ceramics represented by PZT (Pb (lead) zirconate titanate), polymeric piezoelectric elements represented by PVDF (polyvinyl difluoride) and so on. In this embodiment, PZT vibrators are used.

[0037] The ultrasonic transducer **100** includes a vibrator arrangement **10** having a plurality vibrators **11** arranged in a matrix form, an interlayer board **20** for holding the vibrator arrangement **10** and a wiring board **30** formed with electrodes and wiring to apply a voltage to the vibrator arrangement **10** and receive a voltage caused by the vibrator arrangement **10**. The vibrator arrangement **10**, the interlayer board **20** and the wiring board **30** are joined together by solder **21**.

[0038] The vibrator **11** included in the vibrator arrangement **10** has electrodes **12**, **13** formed at respective ends. As the electrode **12**, **13**, there is used, for example, a three-layer electrode formed by evaporating titanium (Ti), platinum (Pt) and gold (Au) in this order. Hereinafter, the electrode thus structured is referred to as a Ti/Pt/Au three-layer electrode.

[0039] Within the electrodes formed on the vibrators **11**, the electrodes **12** formed on a side opposite to the interlayer board may be commonly connected between the plurality of electrodes. In this case, as shown in **FIG. 3, a** common electrode **14** is made by forming a silver thin film over an upper surface of the vibrator arrangement **10**, and a common wiring is provided by bonding a copper plate **15** on one side surface of the vibrator arrangement **10**.

[0040] Referring again to **FIG. 1**, the gaps between the vibrators **11** are filled with a fixing material **16**, for example, of acrylic adhesive, epoxy adhesive or the like. The fixing material **16** holds the vibrators **11** and electrodes **12**, **13** to absorb vibrations of the vibrators **11** thereby promptly reducing the vibrations of the vibrators **11**. This can reduce the ultrasonic interference between the vibrators. Also, the vibrators **11** may be protected by forming the fixing material **16** also along the outer periphery of the matrix-arranged vibrators **11**.

[0041] The interlayer board **20** is an interposed board provided in order to join the vibrator arrangement **10** and the wiring board **30** together. This is formed of, for example, silicon (Si), polyimide or the like.

[0042] The interlayer board **20** has tapered through holes formed in a matrix form in correspondence with the arrangement of the vibrators included in the vibrator arrangement **10**. The through holes are filled with solder **21** to join together the vibrator arrangement **10**, the interlayer board **20** and the wiring board **30**. Namely, the solder **21** connects the electrodes **13** formed on the vibrator **11** to the matrix electrodes **32** formed on the wiring board **30**, respectively. Herein, there may be used as the solder **21** a general solder or a resin-contained solder containing a resin material with a conductive-electrode layer and a solder layer formed around the resin material.

[0043] On the other surface of the interlayer board **20**, an insulating layer **22** is formed. Furthermore, a lattice layer **23** is formed in a manner covering the surface in an area around the matrix-formed through holes. The insulating layer **22** and lattice layer **23** blocks solder such that the solder filled in the through hole does not flow out and contact the solder filled in the adjacent through hole. As the insulating layer **22** and the lattice layer **23**, such a material as insulating resin including polyimide or dielectric insulator including silicon oxide (SiO_2), silicon nitride (SiN) or alumina (Al_2O_3) can be used. These materials, possessing resistance to heat, can be used satisfactorily for a case of using solder having a melting point of nearly 150° C. to 200° C., for example. In this embodiment, an SiO_2 film is used as the insulating layer **22**, while a polyimide insulating film is used as the lattice layer **23**.

[0044] The wiring board **30** is formed of a quartz glass wafer or polyimide, for example. Considering the process of adjusting the position or pitch upon joining together the wiring board **30** and the interlayer board **20** or inspection of joining state, it is desirable to use as the wiring board **30** a material having light transmissivity. Particularly, polyimide is ready to absorb an ultrasonic wave. In case polyimide is used for the wiring board **30**, there is a merit that there is less dissipation of a received ultrasonic wave.

[0045] The wiring board **30** is formed with a wiring layer **31**, a matrix electrodes **32** and pad electrodes **33**. The matrix electrodes **32** are formed in a matrix form in correspondence with the arrangement of the vibrators **11** placed on the interlayer board **20**. Also, the pad electrodes **33** are arranged in a peripheral region of the wiring board **30**. As the wiring layer **31**, the matrix electrodes **32** or the pad electrodes **33**, for example, Ti/Pt/Au three-layer electrodes as mentioned before is used.

[0046] The wiring layer may be protected by forming an insulating layer **34** over the wiring layer **31**. As the insulator layer **34**, such a material as a resin insulator including polyimide or a dielectric insulator including SiO_2, SiN or Al_2O_3 may be used. Otherwise, these materials may be laminated to form an insulating layer **34** having layers of plural kinds of materials. In this embodiment, an SiO_2 film is used as the insulating layer **34**.

[0047] On the wiring layer **31** or insulating layer **34**, a lattice layer **35** is formed at the gaps at between the matrix electrodes **32**. The lattice layer **35** blocks solder such that the solder **21** is not allowed to flow out and short between the adjacent matrix electrodes upon joining together the interlayer board **20** and the wiring board **30**. In this embodiment, polyimide is used as a material of the lattice layer **35**.

[0048] Referring to FIGS. **4** to **9**, explanation is now made on a method of manufacturing an ultrasonic transducer according to a first embodiment of the invention.

[0049] **FIG. 4** is a flowchart showing a fabrication process of a vibrator arrangement in a method of manufacturing an ultrasonic transducer according to the present embodiment. Meanwhile, FIGS. **5A-5C** are views for explaining the fabrication process of a vibrator arrangement.

[0050] At step S11 of **FIG. 4**, electrode materials **111**, **112** are formed on the respective surfaces of a PZT plate **110**, as shown in **FIG. 5A**. In the case of forming a Ti/Pt/Au three-layer electrode, for example, a Ti layer having a thickness of 500 angstroms, a Pt layer having a thickness of 500 angstroms and an Au layer having a thickness of 5000 angstroms are vacuum-evaporated in this order.

[0051] Next, at step S12, the PZT plate formed with electrode materials is fixed by wax on a substrate **150** of Si or the like, and then, the PZT plate is cut as shown in **FIG. 5B**. Cutting is conducted by using, for example, a 0.3 mm-pitch dicer such that the cut vibrators are in a predetermined matrix arrangement.

[0052] Next, at step S13, a fixing material **16** of, for example, acrylic adhesive or epoxy adhesive is filled and fixed in the cut grooves as shown in **FIG. 5C**.

[0053] Furthermore, at step S14, wax is fused to remove the substrate. In this manner, a vibrator arrangement having vibrators arranged in a matrix form is fabricated.

[0054] Referring to FIGS. **6-8D**, explanation is made on a fabrication process of an interlayer board. **FIG. 6** is a flowchart showing a fabrication process of an interlayer board while FIGS. **7A**-**7C** and **8A**-**8D** are views for explaining the fabrication process of an interlayer board.

[**0055**] First, at step **S21** of **FIG. 6**, an SiO_2 layer **121** is formed on a non-doped Si substrate **120** as shown in **FIG. 7A**. Plasma CVD process, for example, can be used in forming the SiO_2 layer **121**.

[**0056**] Next, at step **S22**, a resist pattern **122** is formed on the SiO_2 layer **121** to have openings in a matrix region in correspondence with an arrangement pitch of the vibrators as shown in **FIG. 7B**. A photolithography process is used herein, for example.

[**0057**] At step **S23**, an etching solution of a buffered hydrogen fluoride (BHF) or the like is used to etch the SiO_2 layer in the opened matrix region. This exposes the substrate Si surface in the opened matrix region.

[**0058**] At step **S24**, the resist material formed at step **S22** is removed away by using, for example, acetone as shown in **FIG. 8A**. Furthermore, at step **S25**, a negative photosensitive polyimide layer **123** is formed on a substrate **120** by spin coating, as shown in **FIG. 8B**.

[**0059**] At step **S26**, an ultraviolet ray is radiated to a region except for the matrix region, i.e. lattice region, of the negative photosensitive polyimide layer **123**. This forms a lattice layer and the substrate Si surface is exposed again as shown in **FIG. 8C**.

[**0060**] At step **S27**, anisotropic etching is conducted on the exposed Si surface by using, for example, a potassium hydroxide solution at 80° C. This forms through holes in the Si substrate as shown in **FIG. 8D**.

[**0061**] Referring to FIGS. **9**-**10H**, explanation is now made on a fabrication process of a wiring board. **FIG. 9** is a flowchart showing a fabrication process of a wiring board while FIGS. **10A**-**10H** are views for explaining the fabrication process of a wiring board.

[**0062**] First, at step **S31** of **FIG. 9, a** negative resist layer **131** is formed on a quartz glass wafer (substrate) **130** by using, for example, spin coating, as shown in **FIG. 10A**. Then, at step **S32**, an ultraviolet ray is radiated to a region except for the region to be formed into pad, matrix electrodes and wiring in the negative resist layer **131**, and then development is carried out. Thereafter, the resist layer **131** is made into an inverted-taper form as shown in **FIG. 10B**. Herein, providing an inverted-taper form is in order to readily separate a region to be removed together with the resist layer from a region to be left as electrodes and wiring on the substrate. Because a three-layer metal layer to be subsequently formed is made of materials which are not readily removed by etching.

[**0063**] At step **S33**, an electrode-and-wiring layer **132** is formed on the substrate **130** as shown in **FIG. 1C**. For example, in the case of forming three-layered electrodes and wiring, Ti having a thickness of 500 angstrom, Pt having a thickness of 500 angstrom and Au having a thickness of 5000 angstroms are stacked in this order by a vacuum evaporation process.

[**0064**] Next, at step **S34**, the resist layer formed at step **S31** is removed away by a lift-off technique. This removes also the metal layer formed on the resist. Thus, the electrode-and-wiring layer **132** is left on the quartz glass substrate **130** as shown in **FIG. 10D**.

[**0065**] At step **S35**, an SiO_2 layer **133** having a thickness of 2000 angstrom is formed on the substrate **130** by using a plasma CVD process, as shown in **FIG. 1E**. Next, at step **S36**, a resist pattern is formed by a photolithography process to provide openings in regions of pad electrodes **33** and matrix electrodes **32** (see **FIG. 2**). Furthermore, at step **S37**, etching is conducted by using a BHF solution or the like to remove the SiO_2 layer at the openings, thereby exposing the Au layer of the three-layer-electrode in the opening. Next, removing the resist material formed at step **S36** by using acetone or the like provides a form as shown in **FIG. 10F**. In the case where the insulating layer **34** (see **FIG. 1**) is not provided, steps **S35**-**S38** are omitted.

[**0066**] At step **S39**, a negative photosensitive polyimide layer **134** is formed on the substrate **130** by using, for example, spin coating, as shown in **FIG. 10G**. Next, at step **S40**, an ultraviolet ray is radiated to a lattice portion around the matrix electrode **132**. This forms a lattice layer **35** as shown in **FIG. 10H**.

[**0067**] Referring to FIGS. **11A**-**13**, explanation is now made on a process of joining together the vibrator arrangement, interlayer board and wiring board thus fabricated.

[**0068**] **FIGS. 11A and 11B** are views for explaining a process of joining the vibrator arrangement and the interlayer board together. As shown in **FIG. 11A**, the vibrator arrangement **10** is rested upon a heater plate **2** set up within a quartz chamber **1**, on which the interlayer board **20** is stacked such that the electrodes **13** respectively formed on the vibrators **11** are opposed to the through holes matrix-formed in the interlayer board **20**. The interlayer board **20** is arranged such that the smaller diameter of the taper-formed through hole (the lower in the figure) positions close to the vibrator arrangement **10**. Furthermore, solder balls (ball-formed solder) **21** are respectively put in the through holes of the interlayer board **20**. The solder ball **21** is a low melting solder containing, for example, a material of lead-tin-silver alloy (Pb—Sn—Ag), and has a diameter greater than a thickness of the interlayer board **20** but smaller than the greater diameter of the through hole (the upper in the figure).

[**0069**] Otherwise, the solder **21** may use resin-contained solder. FIGS. **12A**-**12D** are sectional views showing a resin-contained solder. As shown in **FIG. 12A**, the resin-contained solder **21** contains a resin material **21***a*, a conductive electrode layer **21***b* formed on an outer periphery of the resin material **21***a*, and a solder layer **21***c*. As the resin material **21***a*, such a material as divinylbenzene, polyimide, polystyrene, polycarbonate or the like can be used. Meanwhile, as the conductive electrode layer **21***b*, a metal or alloy containing copper or nickel can be used. Furthermore, as the solder layer **21***c*, a material of lead-tin-silver alloy (Pb—Sn—Ag) can be used. As shown in **FIG. 12B**, when such a resin-contained solder is placed between the opposed electrodes **24** and **25** and then heated, the solder layer **21***c* melts to join the electrode **24** and the electrode **25** together. Herein, the resin-contained solder is not limited to a ball form in shape, but may be cubic, columnar, pyramidal or the like as shown in **FIGS. 12C and 12D**.

[**0070**] Referring again to **FIG. 11A**, by filling the quartz chamber **1** with an inert gas such as argon and then energizing the heater plate **2**, temperature of the solder **21** is raised nearly to its melting point (e.g. 120°). Herein, the reason of heating the solder in the inert gas atmosphere is to prevent the solder from being oxidized. Due to this, as shown in **FIG. 11B, a** part (the lower in the figure) of the ball form of the solder **21** melts in the through hole formed in the interlayer board **20** and the melted part is joined to a surface layer (Au layer) of the opposed electrode **13**. At this time, the solder **21** is projected at its upper from the interlayer board **20** while remaining the other part of the ball form. Thereafter, the energization to the heater plate **2** is ceased so as to cool down the vibrator arrangement **10** and interlayer board **20** within the quartz chamber.

[**0071**] **FIG. 13** is a view for explaining a process of joining the interlayer board and the wiring board together.

[**0072**] As shown in **FIG. 13**, the wiring board **30** is stacked such that its surface formed with the electrodes and wiring is directed down, on the interlayer board **20** joined with the vibrator arrangement **10**. Herein, a position of the wiring board **30** is adjusted such that the matrix electrodes **32** formed on the wiring board **30** are respectively opposed to the portions of solder **21** filled in the through holes formed in the interlayer board **20**. In the case where a material possessing light transmissivity such as quartz glass or polyimide is used as the wiring board **30**, position adjustment can be easily carried out by previously providing alignment marks on the board. On the other hand, even in the case where a material not possessing light transmissivity, position adjustment is possible by previously forming alignment marks or through holes on the wiring board **30** or interlayer board **20**.

[**0073**] Again, the quartz chamber **1** is filled with an inert gas such as argon. By energizing the heater plate **2**, temperature of the solder **21** is raised to nearly its melting point. This fuses the other part (the upper in the figure) of the ball form of the solder **21** filled in the through holes formed in the interlayer board **20**, and the other part is joined to the matrix electrodes **32** of the wiring board **30** placed opposed to the solder **21**.

[**0074**] As explained in the above, manufactured is an ultrasonic transducer according to the first embodiment of the invention. Thereafter, wire-bonding is made to connect wiring for providing drive signals for driving the vibrators and receiving detection signals generated by the vibrators to the pad electrodes provided at the peripheral edge of the ultrasonic transducer.

[**0075**] In this embodiment, the interlayer board and the wiring board are joined together after joining the vibrator arrangement and the interlayer board. However, after stacking the vibrator arrangement and the interlayer board together and arranging solder balls, the wiring board may be stacked thereon to simultaneously join them together.

[**0076**] Explanation is now made on an ultrasonic transducer according to a second embodiment of the invention. **FIG. 14** is a sectional view showing an ultrasonic transducer of this embodiment.

[**0077**] As shown in **FIG. 14**, an ultrasonic transducer **200** includes an interlayer board **60** which is structured to have steps. The interlayer board **60** is formed with through holes filled with solder **61**, an insulating layer **62** and a lattice layer **63**, similarly to the first embodiment. Furthermore, a wiring board **70** is formed with a wiring layer **71**, matrix electrodes **72**, pad electrodes **73**, an insulating layer **74** and a lattice layer **75**, similarly to the first embodiment.

[**0078**] A plurality of vibrators **51**, included in a vibrator arrangement **50**, are arranged throughout a plurality of steps provided on the interlayer board **60**. Each vibrator **51** is formed with electrodes **52, 53**. A fixing material **56** is filled between the vibrators **51** to hold the vibrators **51** and absorb the vibrations by an ultrasonic wave.

[**0079**] By thus providing the steps on the vibrator arrangement, interference can be reduced that occurs between near vibrators. The ultrasonic transducer **200** has a plan view similar to **FIG. 2**.

[**0080**] Referring to FIGS. **15** to 19B, explanation is made on a method of manufacturing an ultrasonic transducer according to the second embodiment of the invention. **FIG. 15** is a flowchart showing a manufacturing method of an ultrasonic transducer according to this embodiment. Meanwhile, FIGS. **16A-16D** are views for explaining a fabrication process of an interlayer board having steps.

[**0081**] At step S51 of **FIG. 15, a** resist material **202** is applied to a non-doped Si substrate **201** to carry out a first round of etching by the use of a potassium hydroxide solution at 80° C. or the like, as shown in **FIG. 16A**. By removing the resist material **202** by using acetone or the like, the steps are formed as shown in **FIG. 16B**.

[**0082**] Next, at step S52, a resist material **203** is applied to the substrate **201** formed with one step to carry out a second round of etching by using a potassium hydroxide solution at 80° C. or the like, as shown in **FIG. 16C**. By removing the resist material **203** by using acetone or the like, fabricated is a non-doped Si substrate formed with a plurality of steps, as shown in **FIG. 16D**.

[**0083**] By carrying out the second round of etching, an interlayer board is formed that has a convex form in three steps. In the case of increasing a number of steps, etching may be repeated furthermore.

[**0084**] A vibrator arrangement is formed on the interlayer board having the steps fabricated in this manner. FIGS. **17A-17E** are views for explaining a fabrication process of a vibrator arrangement having the steps. At step S53, electrodes **204** to be used for applying voltages to vibrators are formed on the convex region of the substrate **201**, as shown in **FIG. 17A**. For example, a resist layer, which is opened in the areas where electrodes are to be formed, is formed by a photolithography process or the like. Then, a Ti layer having a thickness of 500 angstrom, a Pt layer having a thickness of 500 angstrom and an Au layer having a thickness of 5000 angstroms are stacked in this order by a vacuum deposition process. By removing the resist layer by lift-off technique, a three-layer electrode is formed.

[**0085**] Next, at step S54, an SiO2 layer **205** is formed on the substrate **201** by a plasma CVD process or the like, as shown in **FIG. 17B**. Thereafter, as shown in **FIG. 17C, a** photolithographic etching process is carried out to remove the SiO_2 layer **205** at the areas of the electrodes **204** formed at step S53.

[**0086**] At step S55, a PZT layer **206** is formed by a sputter process or the like on the substrate **201**, as shown in **FIG. 17D**. Furthermore, at step S56, a Ti/Pt/Au three-layered electrode layer **207** is formed on the PZT layer **206** by a vacuum deposition process or the like, as shown in **FIG. 17E**.

[0087] At step S57, the electrode layer 207 and PZT layer 206 is cut by a dicer having a pitch of, for example, 0.3 mm. Herein, cutting is carried out until reaching the height of the electrode 204. In this manner, vibrators 51 and electrodes 52, 53 are fabricated as shown in FIG. 18A. Furthermore, at step S58, a fixing material 56 of acrylic or epoxy adhesive is filled in the grooves cut by the dicer and fixed. This forms a vibrator arrangement 50 having steps as shown in FIG. 18B.

[0088] Next, at step S59, an SiO_2 layer, a lattice layer and tapered through holes are formed on a substrate surface where the vibrator arrangement is not formed (the upper in the figure) as shown in FIG. 18C. These processes are similar to the processes explained in the first embodiment while referring to FIG. 6. Herein, in this embodiment, the through holes to be filled with solder are formed extending to the electrodes 53. In this manner, an interlayer board 60 is fabricated that is formed with the vibrator arrangement 50.

[0089] Furthermore, at step S60, a wiring board 70 is fabricated. The fabrication process of the wiring board 70 is similar to that of the first embodiment.

[0090] Referring to FIGS. 19A and 19B, explanation is made on a process of joining together the vibrator arrangement and interlayer board thus fabricated.

[0091] As shown in FIG. 19A, the vibrator arrangement 50 and the interlayer board 60 are held in a quartz chamber 3 such that the interlayer board 60 is positioned in the upper. Furthermore, a proper number of solder balls (ball-formed solder) 61 are respectively put in a plurality of through holes formed in the interlayer board 60. The solder ball 61 is made of a low melting solder containing a material of, for example, lead-tin-silver alloy (Pb—Sn—Ag), which has a diameter smaller than the greater diameter of the through hole (the upper in the figure). Herein, as the solder 61 a resin-contained solder may be used which contains a resin material, a conductive electrode layer formed on an outer periphery of the resin material, and a solder layer, similarly to that in the first embodiment.

[0092] Next, the quartz chamber 3 is filled with an inert gas such as argon, to radiate laser light to the solder arranged in the through holes. Due to this, a part (the lower in the figure) of the solder 61 is heated up to nearly its melting point (e.g. 120°) and perfectly joined to the electrodes 53 in a manner being filled in the through holes. At this time, an upper part of the solder 61 is projected from the interlayer board 60 while remaining a part of the ball form. Thereafter, laser light radiation is ceased to cool down the vibrator arrangement 50 and interlayer board 60 within the quartz chamber.

[0093] Next, as shown in FIG. 19B, the interlayer board 60 perfectly joined with the vibrator arrangement is rested on a heater plate 4 set up within the quartz chamber 3. Furthermore, the wiring board 70 is stacked thereto such that its surface formed with electrodes and wiring is directed down. Herein, a position of the wiring board 70 is adjusted in position such that the matrix electrodes 72 formed on the wiring board 70 are opposed to the respective portions of solder 61 filled in the through holes formed in the interlayer board 60.

[0094] Again, the quartz chamber 3 is filled with an inert gas such as argon. By energizing the heater plate 4, temperature of the solder 61 is raised to nearly its melting point. Due to this, the solder 61 is fused and joined with the matrix electrodes 72 on the wiring board 70 placed opposed to the solder 61.

[0095] In this embodiment, steps were provided on the vibrator arrangement to provide the ultrasonic transducer with a convex form. However, steps may be provided in, for example, a concave form such that the vibrator centrally positioned is lower. Namely, the present embodiment can be applied to manufacture an ultrasonic transducer in which a vibrator arrangement has a plurality of steps.

[0096] Further, laser light is used in heating up solder to join the vibrator arrangement and the interlayer board together, and therefore, fusion of the solder can be controlled with accuracy and reproducibility.

[0097] In the first and second embodiments explained above, in the case where wiring is impossible on the wiring board because of an increased number of vibrators, a multi-level wiring may be provided throughout a plurality of wiring layers while providing one or more interlayer insulating film on a wiring board.

[0098] Also, in the first and second embodiments, the vibrators included in the vibrator arrangement are in a two-dimensional matrix form. However, how to arrange them is not limited to that, i.e. a plurality of vibrators may be arranged in a coaxial form.

[0099] Furthermore, in the case of using a resin-contained solder in connecting the electrodes formed on the vibrators to the matrix electrodes formed on the wiring board, the ultrasonic vibrations caused or received by the vibrators are absorbed by the resin material contained in the resin-contained solder. Thus, the acoustic reflection upon the vibrators is reduced to further improve the sensitivity of the ultrasonic transducer and enhance the resolving power thereof.

[0100] As described above, according to the present invention, the provision of an interlayer board makes it possible to easily join electrodes to a multiplicity of micro-fabricated vibrators and provide the electric wiring. Also, the provision of an interlayer board prevents solder from flowing out and provides positive joining at the junction between the vibrator and the wiring, thus improving manufacture yield. Particularly, according to the method of forming tapered through holes in an interlayer board and joining a substrate or the like thereto after putting solder balls in the through holes, there is no fear that the solder ball fall out of the interlayer board, thereby enabling operation with efficiency and positiveness. Accordingly, it is possible to realize a two-dimensional transducer densely integrated with a multiplicity of vibrators. The use of an ultrasonic-application probe including such a two-dimensional transducer makes possible to obtain an ultrasonic image with quality.

1. An ultrasonic transducer comprising:

a vibrator arrangement having a plurality of vibrators, each formed with first and second electrodes, provided in a predetermined arrangement;

a first board for holding the vibrator arrangement, said first board being formed with a plurality of through holes in positions corresponding to the second electrodes of the vibrators; and a second board formed with a plurality of electrodes electrically connected to the second electrodes of the plurality of vibrators through the plurality of through holes of the first board, respectively.

2. An ultrasonic transducer according to claim 1, wherein the plurality of vibrators are arranged in a two-dimensional matrix form.

3. An ultrasonic transducer according to claim 1, wherein the plurality of vibrators are arranged on a same plane.

4. An ultrasonic transducer according to claim 1, wherein the first board has a plurality of steps, and the plurality of vibrators are arranged on the plurality of steps of the first board.

5. An ultrasonic transducer according to claim 1, wherein the first board includes one of a silicon substrate and a polyimide substrate.

6. An ultrasonic transducer according to claim 1, wherein each of the plurality of through holes formed in the first board has a taper form.

7. An ultrasonic transducer according to claim 1, wherein the first board includes an insulating layer formed around the plurality of through holes.

8. An ultrasonic transducer according to claim 7, wherein the insulating layer includes at least one of an insulating resin film including polyimide resin and a dielectric insulating film including one of silicon oxide (SiO_2), silicon nitride (SiN) and alumina (Al_2O_3).

9. An ultrasonic transducer according to claim 1, wherein the second board has light transmissivity.

10. An ultrasonic transducer according to claim 9, wherein the second board includes one of a quartz glass substrate and a polyimide substrate.

11. An ultrasonic transducer according to claim 1, wherein the second board has an insulating layer formed around a region where the plurality of electrodes are formed.

12. An ultrasonic transducer according to claim 11, wherein the insulating layer includes at least one of an insulating resin film including polyimide resin and a dielectric insulating film including one of silicon oxide (SiO_2), silicon nitride (SiN) and alumina (Al_2O_3).

13. An ultrasonic transducer according to claim 1, wherein the second electrodes of the plurality of vibrators and the plurality of electrodes formed on the second board are respectively connected to each other by using a resin-contained solder including a resin material with a conductive-electrode layer and a solder layer formed on the resin material.

14. A method of manufacturing an ultrasonic transducer, said method comprising the steps of:

(a) preparing a first board formed with a plurality of through holes in predetermined positions;

(b) arranging a plurality of vibrators, each formed with first and second electrodes, onto a first surface of the first board;

(c) arranging a second board, formed with a plurality of electrodes, onto a second surface of the first board; and

(d) arranging solder in the plurality of through holes formed in the first board and respectively joining the second electrodes of the plurality of vibrators to the plurality of electrodes of the second board through the plurality of through holes formed in the first board by using the solder.

15. A method of manufacturing an ultrasonic transducer according to claim 14, whereat step (a) includes forming an insulating layer around the plurality of through holes formed in the first board.

16. A method of manufacturing an ultrasonic transducer according to claim 14, whereat step (a) includes forming a plurality of taper-formed through holes in the first board by using anisotropic etching.

17. A method of manufacturing an ultrasonic transducer according to claim 14, whereat step (b) includes cutting a vibrator plate at a predetermined pitch so as to fabricate the plurality of vibrators.

18. A method of manufacturing an ultrasonic transducer according to claim 14, whereat step (b) includes arranging the plurality of vibrators on a same plane.

19. A method of manufacturing an ultrasonic transducer according to claim 14, whereat step (a) includes forming a plurality of steps on the first board, and step (b) includes arranging the plurality of vibrators on the plurality of steps of the first board.

20. A method of manufacturing an ultrasonic transducer according to claim 14, whereat step (c) includes forming an insulating layer around a region where the plurality of electrodes are formed in the second board.

21. A method of manufacturing an ultrasonic transducer according to claim 14, whereat step (d) includes the steps of:

stacking the plurality of vibrators, the first board having solder balls arranged in the through holes and the second board; and

simultaneously joining together the vibrators, the first board and the second board by fusing the solder balls.

22. An ultrasonic transducer according to claim 14, whereat step (d) includes the steps of:

stacking the plurality of vibrators on a first surface of the first board arranged with solder balls in the through holes;

fusing the solder balls while remaining a part of a ball form of the solder balls thereby filling solder in the plurality of through holes and joining the vibrators to the first board;

stacking the second board on a second surface of the first board; and

fusing the part of the ball form of the solder balls thereby joining the second board to the first board.

23. An ultrasonic transducer according to claim 14, whereat step (d) includes fusing the solder by using laser light.

24. A method of manufacturing an ultrasonic transducer according to claim 14, whereat step (d) includes arranging a resin-contained solder including a resin material with a conductive-electrode layer and a solder layer formed on the resin material into the plurality of through holes formed in the first board.

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专利名称(译)	超声换能器及其制造方法		
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[标]发明人	KUNIYASU TOSHIAKI HARADA AKINORI NAKAMURA TAKASHI		
发明人	KUNIYASU, TOSHIAKI HARADA, AKINORI NAKAMURA, TAKASHI		
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摘要(译)

可以容易且积极地提供一种超声换能器，其中电极可以容易地和形状地连接到多个微制造的振动器和电线上。超声换能器具有振动器装置，该振动器装置具有多个振动器，每个振动器形成有第一和第二电极，以预定的布置设置;用于保持振动器装置的夹层板，其中多个通孔分别形成在与振动器的第二电极相对应的位置;和形成有多个电极的布线板，所述多个电极分别通过夹层板的通孔电连接到振动器的第二电极。