US 20060119226A1

(19) **United States**

(12) **Patent Application Publication** (10) **Pub. No.: US 2006/0119226 A1**

Nihei (43) **Pub. Date: Jun. 8, 2006**

(54) **PIEZOELECTRIC ACTUATOR, METHOD OF MANUFACTURING SAME, AND LIQUID EJECTION HEAD**

(75) Inventor: **Yasukazu Nihei**, Ashigara-Kami-Gun (JP)

Correspondence Address:
BIRCH STEWART KOLASCH & BIRCH
PO BOX 747
FALLS CHURCH, VA 22040-0747 (US)

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

(21) Appl. No.: **11/290,643**

(22) Filed: **Dec. 1, 2005**

(30) **Foreign Application Priority Data**

Dec. 3, 2004 (JP) 2004-351209

Publication Classification

(51) **Int. Cl.**
H01L 41/08 (2006.01)

(52) **U.S. Cl.** **310/341**

(57) **ABSTRACT**

The piezoelectric actuator comprises: a supporting substrate; a thermal stress controlling layer which is formed on the supporting substrate; and a piezoelectric body which is formed as a film onto the thermal stress controlling layer on the supporting substrate at a higher temperature than room temperature, wherein the thermal stress controlling layer reduces a film stress induced by formation of the piezoelectric body.

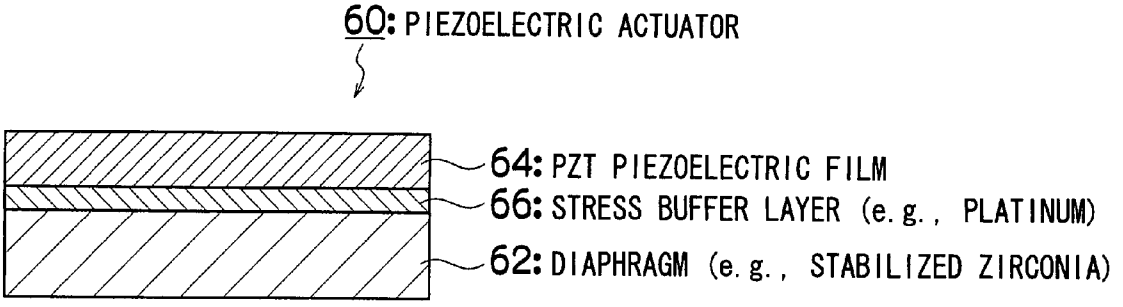


FIG.1

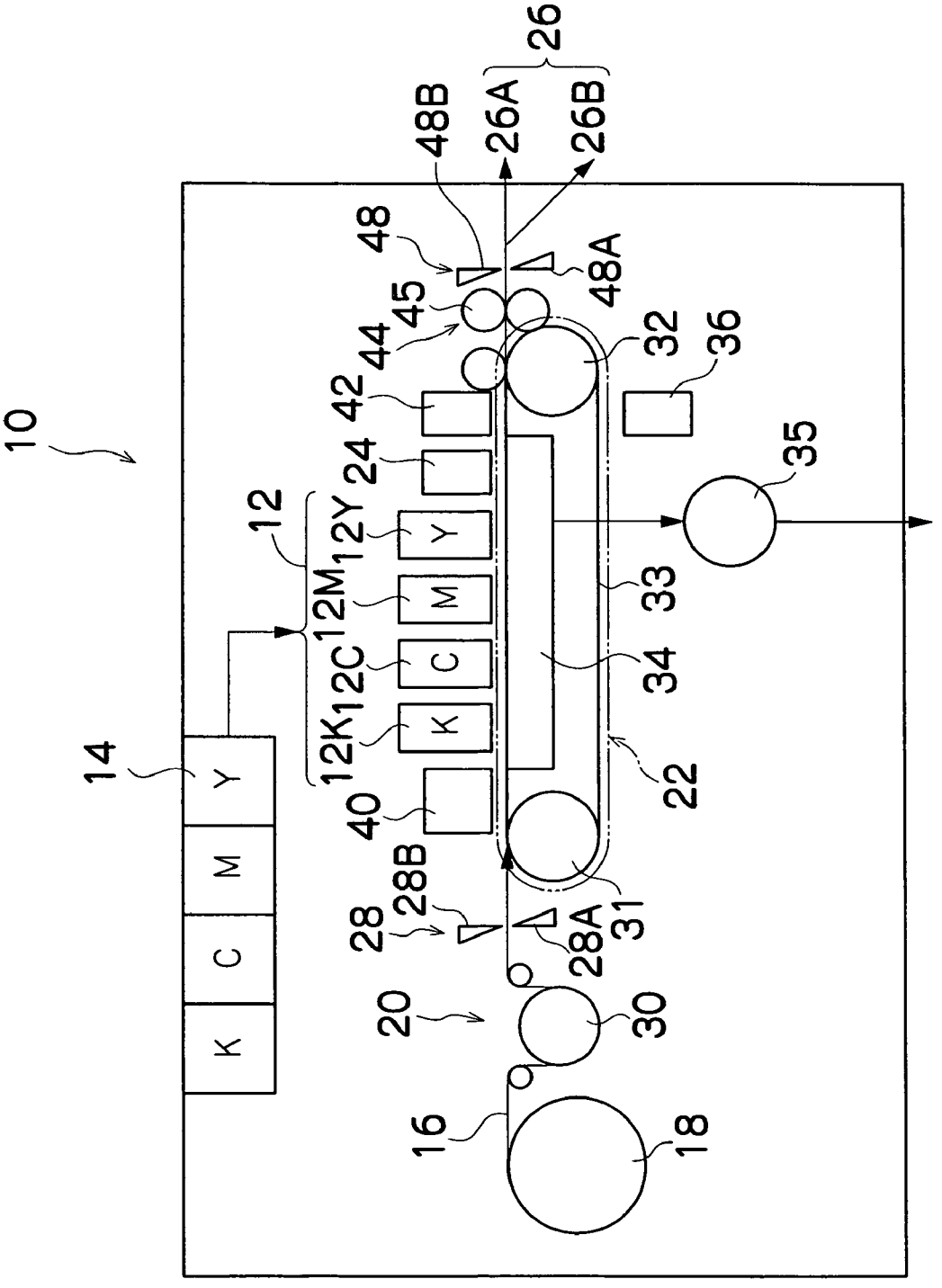

10
12
12Y
12M
12C
12K
14
16
18
20
22
24
26
26A
26B
28
28A
28B
30
31
32
33
34
35
36
40
42
44
45
48
48A
48B
Y
M
C
K

FIG.2

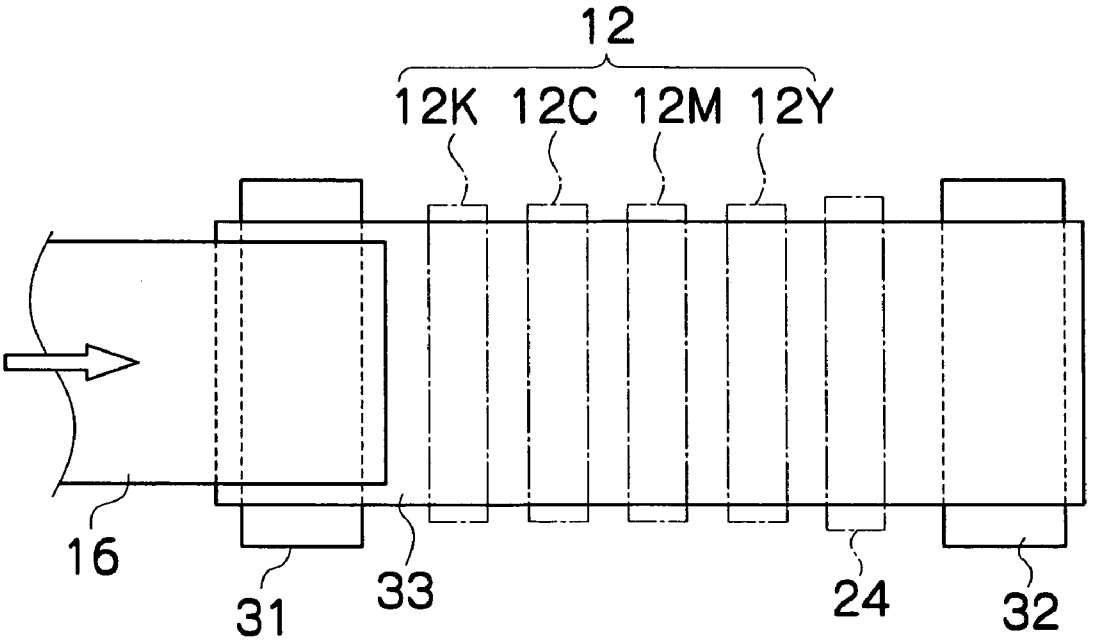


FIG.3

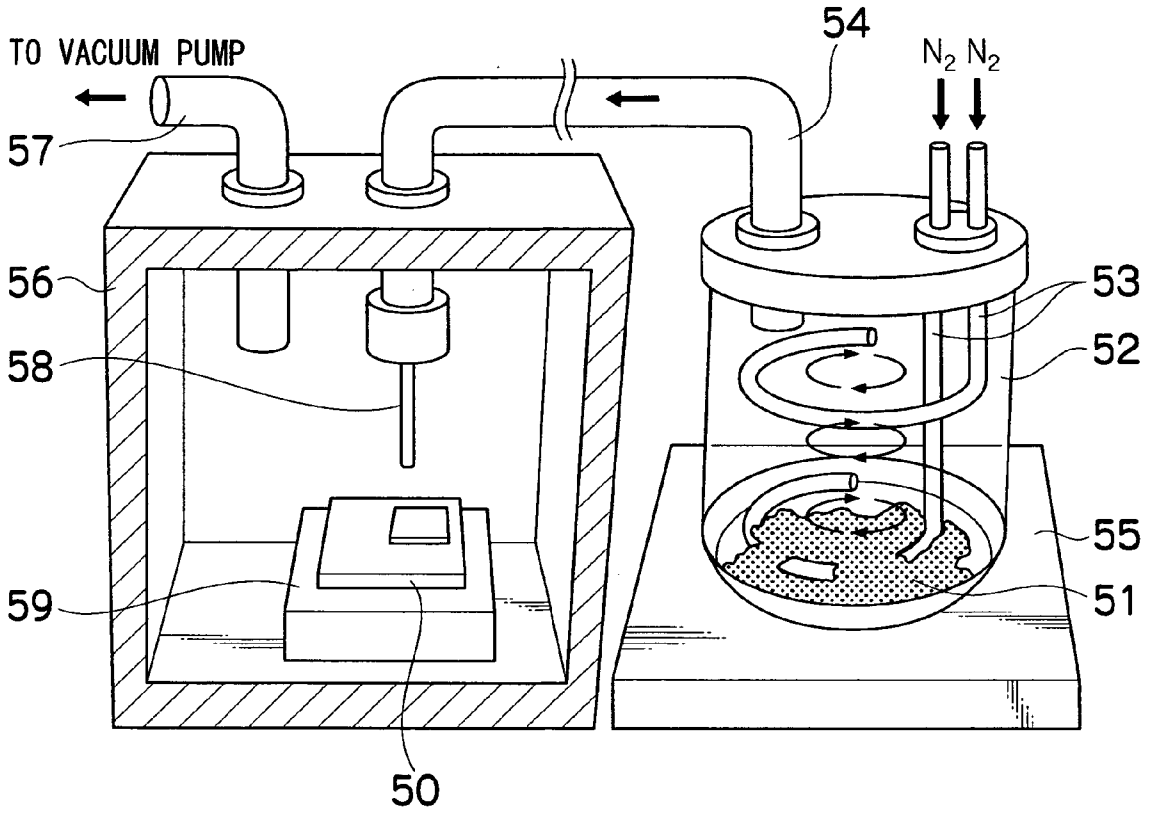


FIG.4A

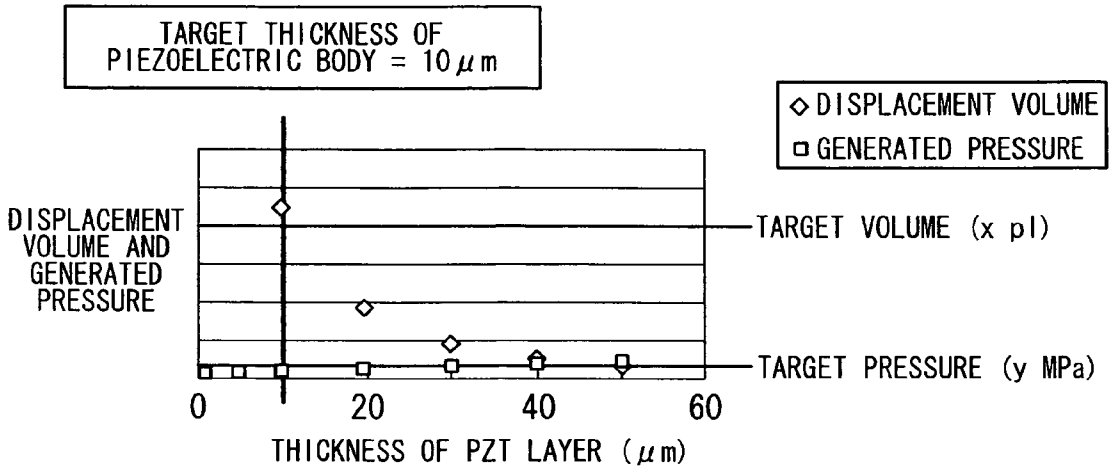
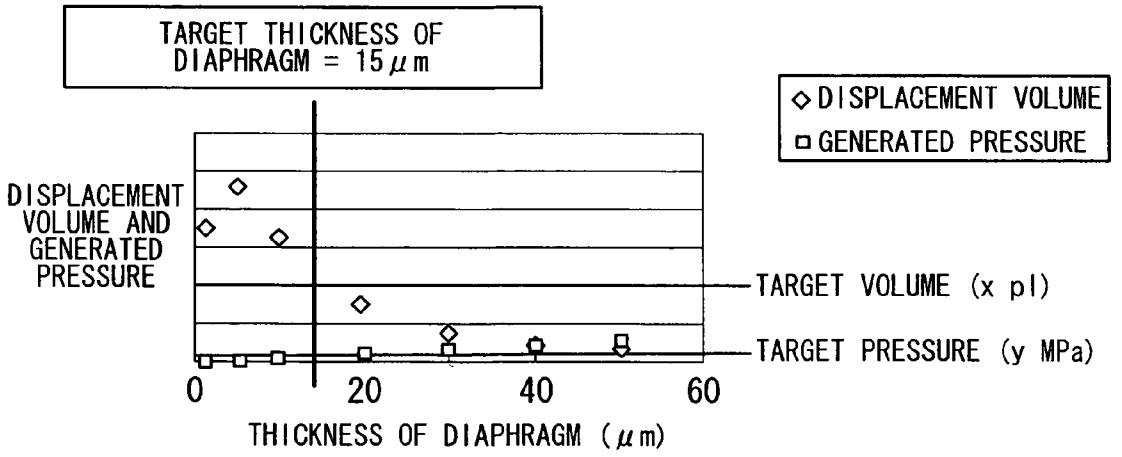


FIG.4B



DIMENSIONS OF PIEZOELECTRIC BODY: 300 μm SQUARE
PIEZOELECTRIC CONSTANT: 250 pm/V

FIG.5

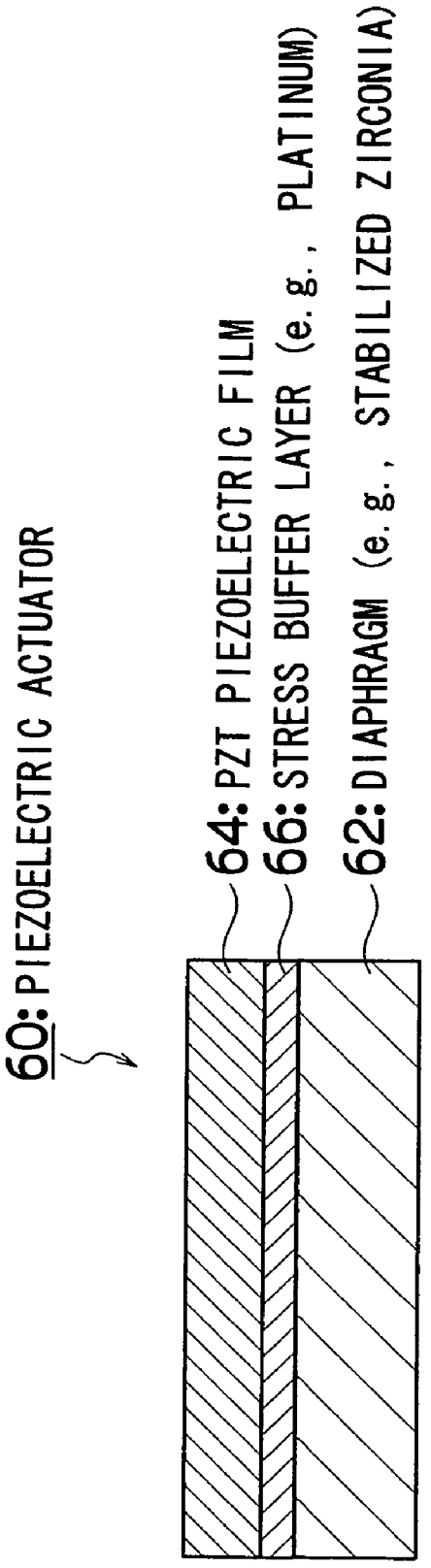

60: PIEZOELECTRIC ACTUATOR
64: PZT PIEZOELECTRIC FILM
66: STRESS BUFFER LAYER (e.g., PLATINUM)
62: DIAPHRAGM (e.g., STABILIZED ZIRCONIA)

FIG.6

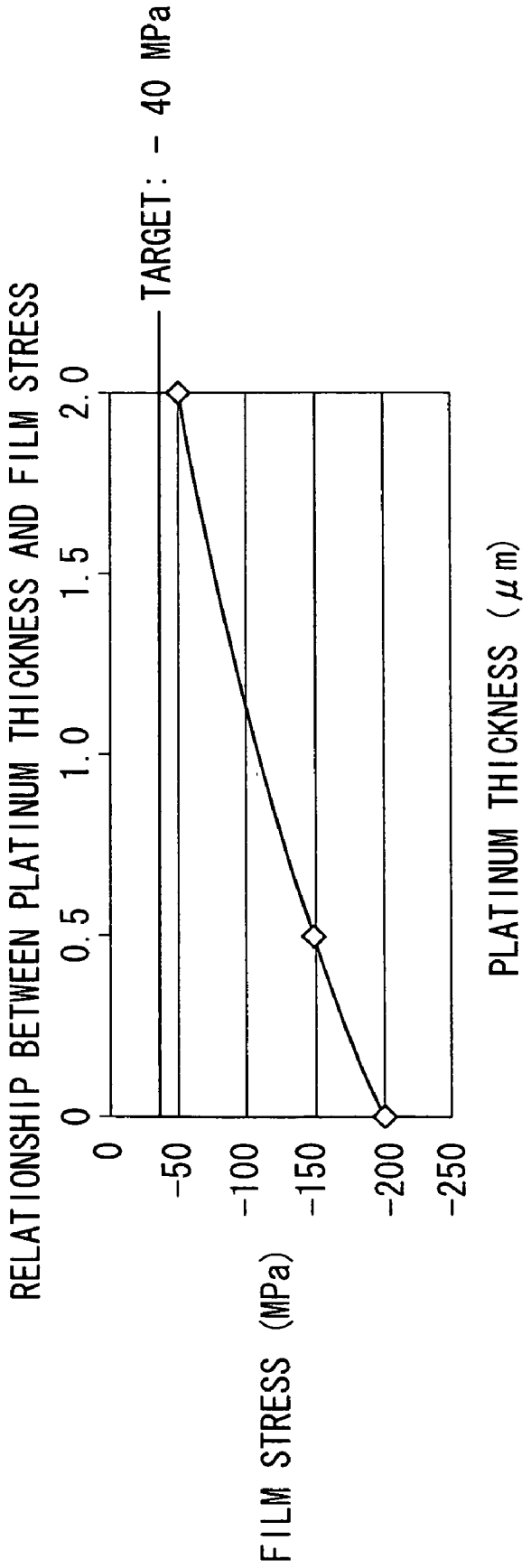

RELATIONSHIP BETWEEN PLATINUM THICKNESS AND FILM STRESS
TARGET: - 40 MPa
0
0.5
1.0
1.5
2.0
PLATINUM THICKNESS (μm)
0
-50
-100
-150
-200
-250
FILM STRESS (MPa)

FIG.7

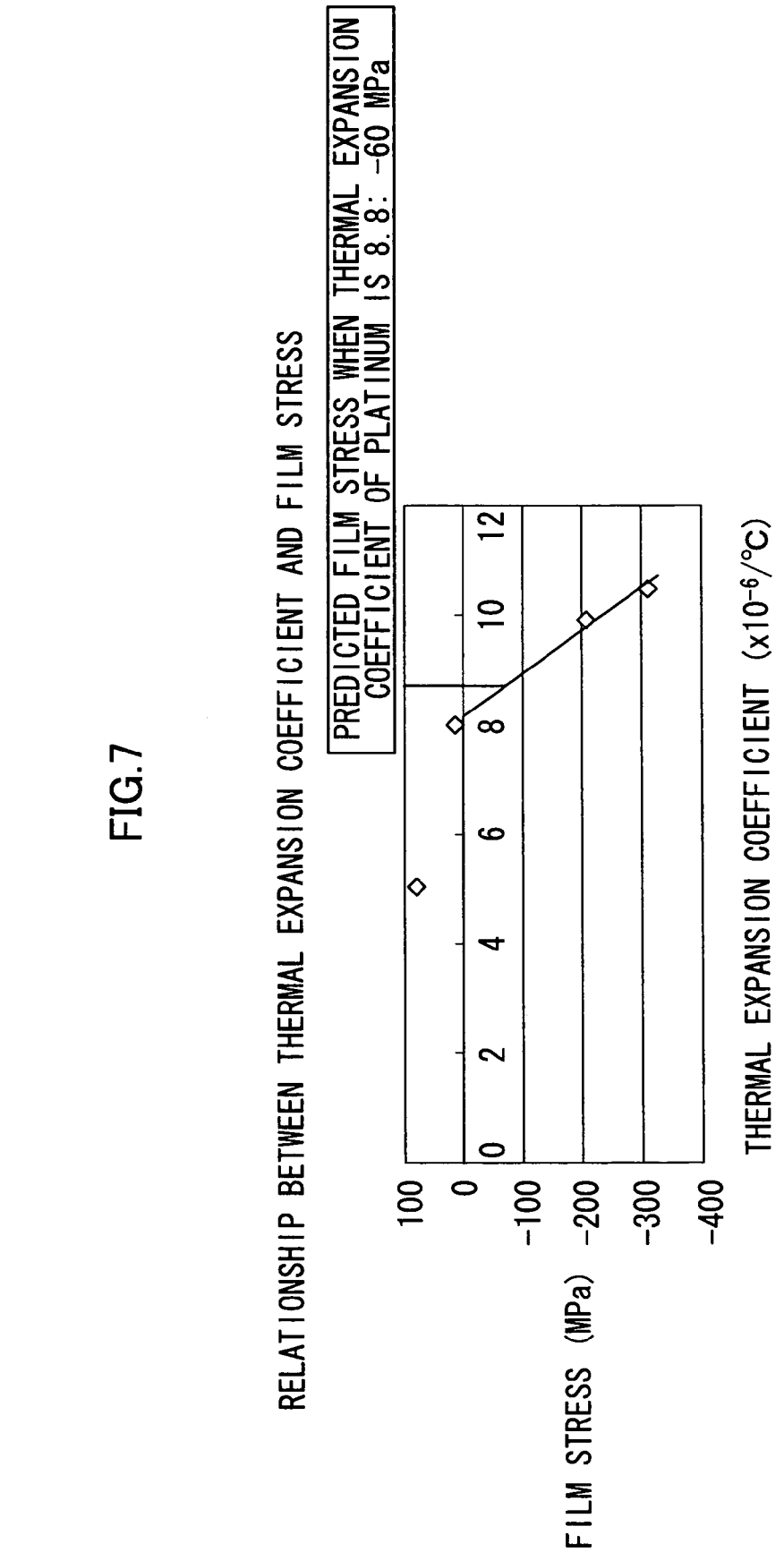

RELATIONSHIP BETWEEN THERMAL EXPANSION COEFFICIENT AND FILM STRESS
PREDICTED FILM STRESS WHEN THERMAL EXPANSION COEFFICIENT OF PLATINUM IS 8.8: -60 MPa
FILM STRESS (MPa)
100
0
-100
-200
-300
-400
0
2
4
6
8
10
12
THERMAL EXPANSION COEFFICIENT (x10-6/°C)

FIG.8

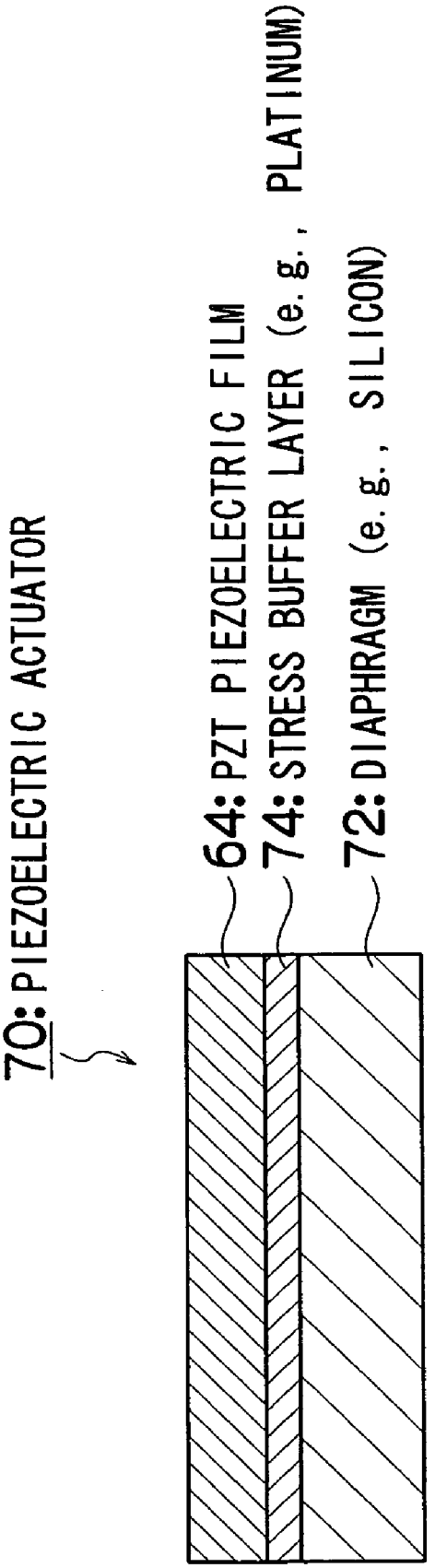

70: PIEZOELECTRIC ACTUATOR
64: PZT PIEZOELECTRIC FILM
74: STRESS BUFFER LAYER (e.g., PLATINUM)
72: DIAPHRAGM (e.g., SILICON)

FIG.9

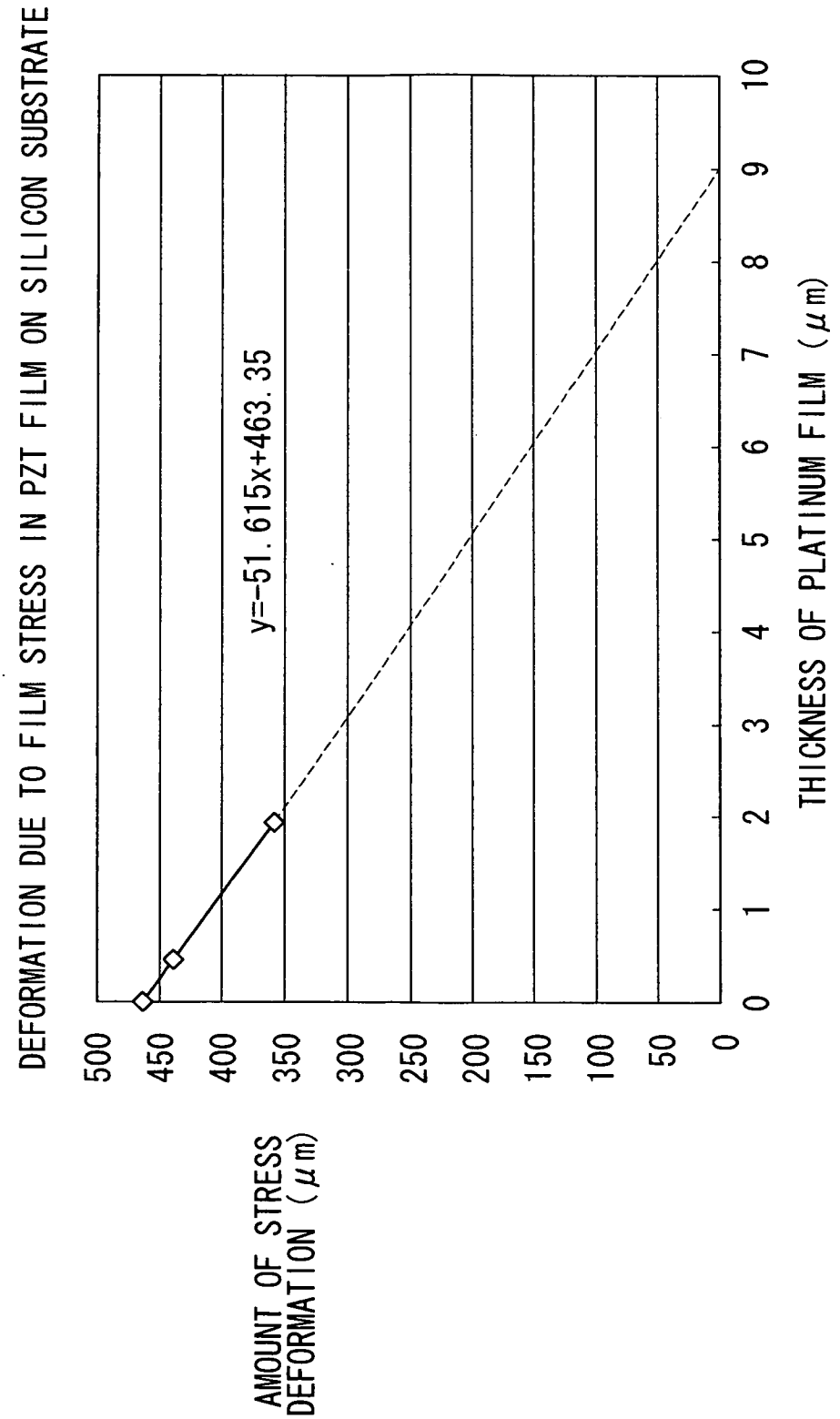

DEFORMATION DUE TO FILM STRESS IN PZT FILM ON SILICON SUBSTRATE
y=-51.615x+463.35
AMOUNT OF STRESS DEFORMATION (μm)
500
450
400
350
300
250
200
150
100
50
0
0
1
2
3
4
5
6
7
8
9
10
THICKNESS OF PLATINUM FILM (μm)

FIG.10

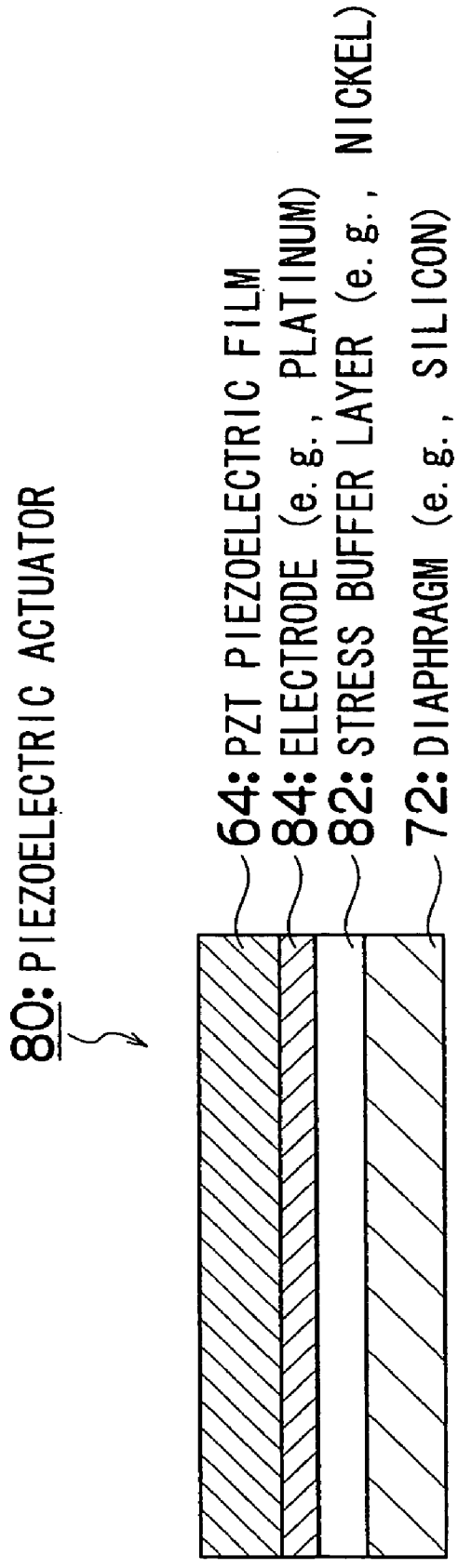

80: PIEZOELECTRIC ACTUATOR
64: PZT PIEZOELECTRIC FILM
84: ELECTRODE (e.g., PLATINUM)
82: STRESS BUFFER LAYER (e.g., NICKEL)
72: DIAPHRAGM (e.g., SILICON)

FIG.11

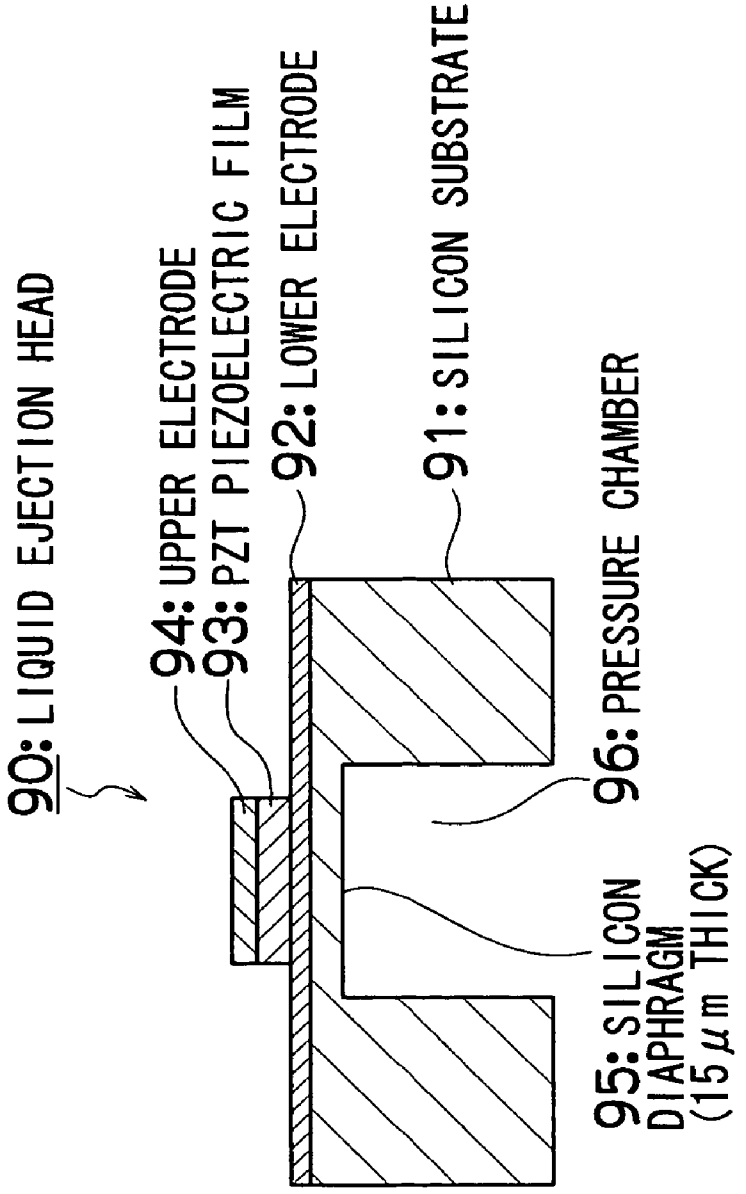
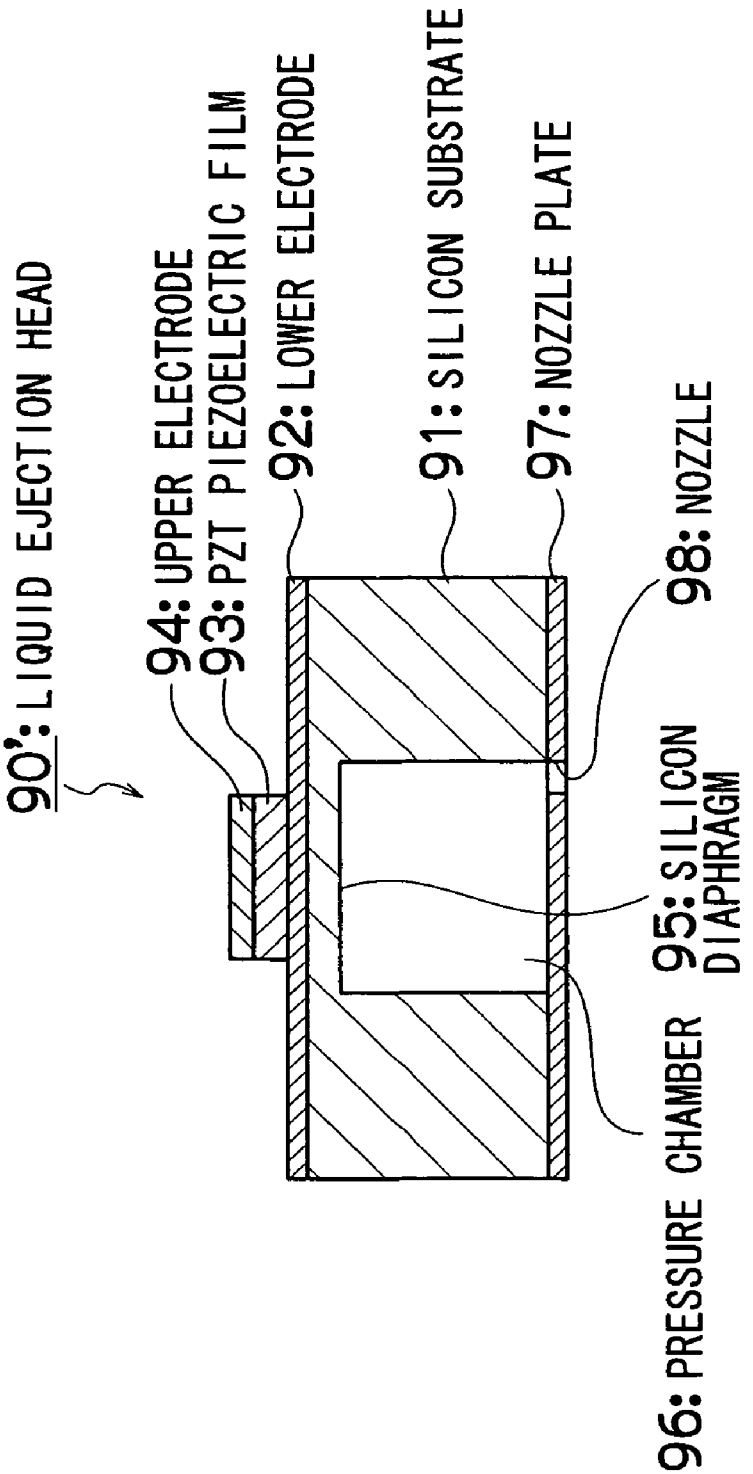

90: LIQUID EJECTION HEAD
94: UPPER ELECTRODE
93: PZT PIEZOELECTRIC FILM
92: LOWER ELECTRODE
91: SILICON SUBSTRATE
96: PRESSURE CHAMBER
95: SILICON DIAPHRAGM (15 μm THICK)

FIG.12


90': LIQUID EJECTION HEAD
94: UPPER ELECTRODE
93: PZT PIEZOELECTRIC FILM
92: LOWER ELECTRODE
91: SILICON SUBSTRATE
97: NOZZLE PLATE
98: NOZZLE
95: SILICON DIAPHRAGM
96: PRESSURE CHAMBER

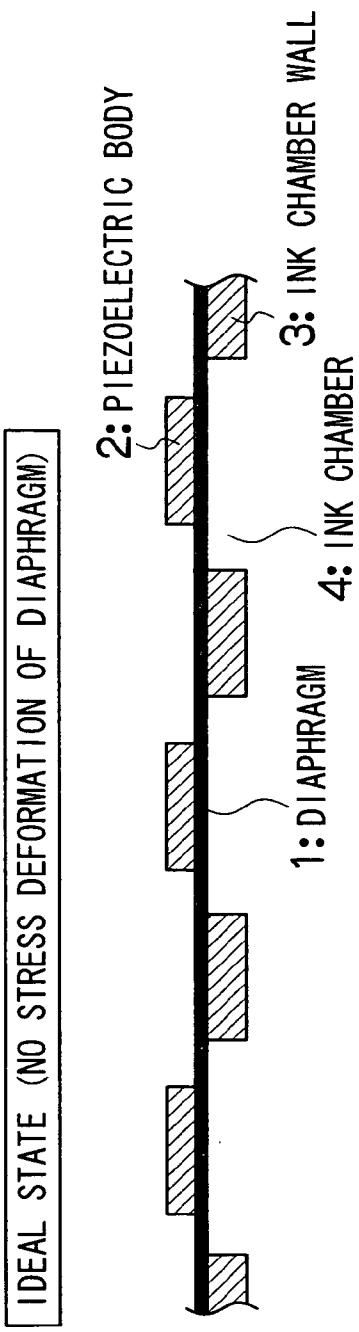


FIG.13A

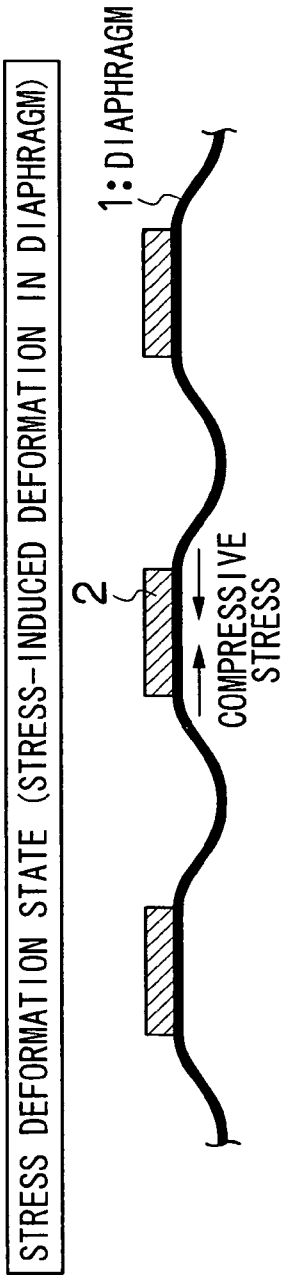


FIG.13B

PIEZOELECTRIC ACTUATOR, METHOD OF MANUFACTURING SAME, AND LIQUID EJECTION HEAD

BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention

[0002] The present invention relates to a piezoelectric actuator, a method of manufacturing same, and a liquid ejection head, and more particularly to technologies that can reduce a thermal stress induced by film formation of a piezoelectric body.

[0003] 2. Description of the Related Art

[0004] Conventionally, the principal method of manufacturing an inkjet head is a method which involves bonding a bulk polished piezoelectric body member (made of lead zirconate titanate ($Pb(ZrTi)O_3$) (PZT), for example) and a calcined green sheet, to a diaphragm plate, by means of an adhesive. In this case, there is no need to take account of thermal stress in the piezoelectric body.

[0005] Furthermore, in a method of manufacturing inkjet head described in Japanese Patent Application Publication No. 2003-309299, a piezoelectric film is grown epitaxially on an epitaxial substrate, a silicon substrate is bonded directly to the opposite side of the piezoelectric film, and then the epitaxial substrate is separated from the piezoelectric film. In this case, the thermal stress induced on the boundary between the piezoelectric film and the epitaxial substrate by the formation of the piezoelectric film can be eliminated by removing the epitaxial substrate.

[0006] Moreover, recently, it is necessary to form the piezoelectric body as a thin film in accordance with increasing density in inkjet heads. Therefore, there are various examples that a piezoelectric body is formed on a diaphragm plate by the sputtering method.

[0007] On the other hand, recently, in the field of micro electrical mechanical systems (MEMS), technologies are suggested that elements such as sensors and actuators are integrated in yet higher levels by using piezoelectric ceramic, and are forming films on those elements in order to achieve practical use. An aerosol deposition method receives attention in those technologies, which is known as a film formation technique for use with ceramics, metals, and the like.

[0008] The aerosol deposition method is a method in which an aerosol is generated from a powder of raw material, the aerosol is sprayed onto a substrate, and a film is formed by deposition of the powdered material due to its impact energy. It is also called a "spray volume method" or a "gas deposition volume method".

[0009] When manufacturing a liquid ejection head, such as an inkjet head, it is proposed that a piezoelectric body and the like may be formed by the aerosol deposition method described above (see Japanese Patent Application Publication No. 2003-136714).

[0010] The film thickness of a piezoelectric body formed by the sputtering method on a diaphragm is approximately 3 μm. Therefore, since the film is thin, it does not give rise to notable deformation of the diaphragm even if there is stress in the film. Hence, no particular importance is attached to controlling stress in the film.

[0011] On the other hand, if a piezoelectric body or the like is formed by the aerosol deposition method, as described in Japanese Patent Application Publication No. 2003-136714, a strong compressive stress acts in the aerosol deposition film which has a fine structure, and the temperature during aerosol deposition film formation is approximately 600° C. Therefore, thermal stress acts on the film after film formation due to the difference between thermal expansion coefficients of the piezoelectric body and the diaphragm, and in particular, when the film is formed on a thin diaphragm having a thickness of 30 μm or less, then the diaphragm deforms due to the stress. Furthermore, if the film thickness of the piezoelectric body is 1 μm or more, and more particularly, approximately 10 μm, then the deformation due to stress in the film occurs remarkably.

[0012] **FIG. 13A** shows an ideal state in which there is no film stress in a piezoelectric body **2** formed on a diaphragm **1**, so that there is no deformation of the diaphragm **1**. **FIG. 13B** shows a state where a compressive stress acts on the piezoelectric body **2**, so that the diaphragm **1** deforms unevenly due to the stress.

[0013] When stress deformation occurs in the diaphragm **1** as shown in **FIG. 13B**, there are following problems.

[0014] (1) Since a gap arises when the diaphragm **1** is bonded to the ink chamber partitions **3**, the following problems arise, consequently.

[0015] a) Since the ink chambers **4** cannot be divided by the ink chamber partitions **3**, then there is movement of ink between adjacently positioned ink chambers **4**, and ink may gather in the gaps, thereby making it impossible to control the volume of ink that is ejected from the nozzles.

[0016] b) Since regions where the diaphragm **1** is not fixed to the ink chamber partitions **3** arise, then variations occur in the displacement volume and torque, and hence image defects arise due to non-uniformities in ink ejection throughout the surface.

[0017] c) Since the diaphragm **1** and the ink chamber partitions **3** can not be reliably fixed by bonding, then long-term durability cannot be guaranteed.

[0018] (2) Since deformation occurs in the diaphragm **1**, then the volume of the ink chamber **4** varies, and variation may arise in the ejected ink volume even if the diaphragm **1** is driven at the same displacement volume, whereby image defects may occur due to non-uniformities in ink ejection throughout the surface.

[0019] (3) When deformation occurs in the diaphragm **1**, sufficient alignment accuracy is not obtained in the subsequent process of wiring to the electrodes for driving the piezoelectric bodies **2**, whereby wiring defects arise.

SUMMARY OF THE INVENTION

[0020] The present invention was devised in view of the aforementioned circumstances, an object thereof being to provide a piezoelectric actuator, a method of manufacturing same, and a liquid ejection head that can reduce either the film stress in piezoelectric bodies formed onto a supporting

substrate and the deformation of the supporting substrate, without restricting the material of the support substrate.

[0021] In order to attain the aforementioned object, the present invention is directed to a piezoelectric actuator comprising: a supporting substrate; a thermal stress controlling layer which is formed on the supporting substrate; and a piezoelectric body which is formed as a film onto the thermal stress controlling layer on the supporting substrate at a higher temperature than room temperature, wherein the thermal stress controlling layer reduces a film stress induced by formation of the piezoelectric body.

[0022] In the case in which no thermal stress controlling layer is interposed between the supporting substrate and the piezoelectric body, a thermal stress acts on the piezoelectric body when the piezoelectric body returns to normal temperature after film formation of the piezoelectric body, due to the difference between thermal expansion coefficients of the supporting substrate and the piezoelectric body, and the temperature difference between normal temperature and a temperature during film formation. In this case, a stress (compressive stress) also acts on the actual piezoelectric body. However, according to the present invention, since the thermal stress controlling layer is interposed, then the film stress in the piezoelectric body is reduced, and deformation of the supporting substrate is suppressed. Incidentally, it is considered that the stress of the piezoelectric body can be reduced by selecting a supporting substrate having a thermal expansion coefficient which is close to the thermal expansion coefficient of the piezoelectric body, but in this case, a restriction is placed on the thermal expansion coefficient of the supporting substrate, in addition to the durability, processability, and vibration characteristics (such as Young's modulus) of the supporting substrate. The present invention can increase choice flexibility of materials which can be used as the supporting substrate, without restricting the thermal expansion coefficient of the supporting substrate.

[0023] The present invention is also directed to the piezoelectric actuator wherein: the thermal stress controlling layer has a thermal expansion coefficient which is selected according to a first thermal expansion coefficient and a second thermal expansion coefficient, the first thermal expansion coefficient being a thermal expansion coefficient of piezoelectric body, the second thermal expansion coefficient being a thermal expansion coefficient of the supporting substrate. In other words, the layer having a thermal expansion coefficient which can reduce thermal stress of the piezoelectric body is selected as the thermal stress controlling layer.

[0024] The present invention is also directed to the piezoelectric actuator wherein: when the second thermal expansion coefficient is higher than the first thermal expansion coefficient, the thermal stress controlling layer has a thermal expansion coefficient which is lower than the second thermal expansion coefficient. Therefore, it is possible to decrease a difference between thermal expansion coefficients of the piezoelectric body and the thermal stress controlling layer on the supporting substrate.

[0025] The present invention is also directed to the piezoelectric actuator wherein: when the second thermal expansion coefficient is higher than the first thermal expansion coefficient, the thermal stress controlling layer has a thermal expansion coefficient which is lower than the first thermal expansion coefficient. According to the present invention, it is possible to allow the thermal stress controlling layer to cancel out the true stress in the piezoelectric film and the thermal stress.

[0026] The present invention is also directed to the piezoelectric actuator wherein: when the second thermal expansion coefficient is lower than the first thermal expansion coefficient, the thermal stress controlling layer has a thermal expansion coefficient which is higher than the second thermal expansion coefficient. Accordingly, it is possible to decrease a difference between thermal expansion coefficients of the piezoelectric body and the thermal stress controlling layer on the supporting substrate.

[0027] The present invention is also directed to the piezoelectric actuator wherein: when the second thermal expansion coefficient is lower than the first thermal expansion coefficient, the thermal stress controlling layer has a thermal expansion coefficient which is higher than the first thermal expansion coefficient. Accordingly, it is possible to allow the thermal stress controlling layer to cancel out the true stress in the piezoelectric film and the thermal stress.

[0028] The present invention is also directed to the piezoelectric actuator wherein the thermal stress controlling layer has a prescribed thickness required for reducing a thermal stress remaining in the piezoelectric body. As a thickness of the thermal stress controlling layer increases, the thermal expansion coefficient of the thermal stress controlling layer is more dominant than the thermal expansion coefficient of the supporting substrate.

[0029] The present invention is also directed to the piezoelectric actuator wherein the thermal stress controlling layer also serves as an electrode for driving the piezoelectric body.

[0030] The present invention is also directed to the piezoelectric actuator wherein an electrode which drives the piezoelectric body is formed between the thermal stress controlling layer and the piezoelectric body. This electrode can account for a part of the thermal stress controlling layer, depending on the thickness thereof.

[0031] The present invention is also directed to the piezoelectric actuator wherein a thickness of the supporting substrate is 30 μm or less.

[0032] The present invention is also directed to the piezoelectric actuator wherein a thickness of the piezoelectric body is 1 μm or greater.

[0033] More specifically, in a piezoelectric actuator for achieving a piezoelectric inkjet head having a high precision and a high-torque, it is important that a thick film of piezoelectric body of 1 μm or greater (preferably, approximately 10 μm) be formed directly onto a thin supporting substrate (diaphragm) having a thickness of 30 μm or less (preferably, approximately 15 μm).

[0034] The present invention is also directed to the piezoelectric actuator wherein the piezoelectric body is formed by an aerosol deposition method. Since the piezoelectric body is formed by the aerosol deposition method, it is possible to form the piezoelectric body having a thickness which can not be formed by the spattering method, for example.

[0035] The present invention is also directed to the piezoelectric actuator wherein: the piezoelectric body formed by

the aerosol deposition method is a PZT piezoelectric film; and a crystal a-axis length of the PZT piezoelectric film is in the range of 2.025 to 2.040 Angstroms. When the crystal a-axis length of the PZT piezoelectric film is in the range of 2.025 to 2.040 Angstroms, it is possible to prevent the supporting substrate from being deformed largely by the film stress in the PZT piezoelectric film.

[0036] The present invention is also directed to the piezoelectric actuator wherein the thermal stress controlling layer is formed by at least one of a sputtering method, a plating method, and an aerosol deposition method. When the thermal stress controlling layer is formed by the aerosol deposition method, it is necessary to reduce the film stress in the thermal stress controlling layer. In order to reduce the film stress, for example, the thermal stress controlling layer is formed not to have a fine structure, such as a piezoelectric film, or the film thickness and the materials for the thermal stress controlling layer are chosen.

[0037] The present invention is also directed to the piezoelectric actuator wherein: the supporting substrate is made of stabilized zirconia; and the thermal stress controlling layer is made of platinum having a thickness of 2 to 5 μm. Generally, platinum has a thickness of 100 nm for forming the electrode, but the platinum thickness of 2 to 5 μm is needed for having function of the thermal stress controlling layer. The thermal stress controlling layer having a thickness in this range can be formed by the aerosol deposition method.

[0038] The present invention is also directed to the piezoelectric actuator wherein: the supporting substrate is made of stabilized zirconia; and the thermal stress controlling layer is made of iridium having a thickness of 1 to 5 μm. Since a thermal expansion coefficient of iridium is smaller than that of platinum, then the thermal stress controlling layer of iridium can have a thinner thickness than the thermal stress controlling layer of platinum.

[0039] The present invention is also directed to the piezoelectric actuator wherein: the supporting substrate is made of silicon; and the thermal stress controlling layer is made of platinum having a thickness of 10 μm or less.

[0040] The present invention is also directed to the piezoelectric actuator wherein: the supporting substrate is made of silicon; and the thermal stress controlling layer is made of nickel having a thickness of 1 to 5 μm.

[0041] The present invention is also directed to the piezoelectric actuator wherein: the supporting substrate is made of silicon; and the thermal stress controlling layer is made of titanium oxide having a thickness of 2 to 5 μm. Since a thermal expansion coefficient of titanium oxide is smaller than that of nickel, then the thermal stress controlling layer of titanium oxide is thicker than the thermal stress controlling layer of nickel.

[0042] In order to attain the aforementioned object, the present invention is directed to a liquid ejection head comprising: a pressure chamber which fills with a liquid; a nozzle which ejects the liquid from the pressure chamber; and a piezoelectric actuator which comprises a supporting substrate; a thermal stress controlling layer which is formed on the supporting substrate; and a piezoelectric body which is formed as a film onto the thermal stress controlling layer on the supporting substrate at a higher temperature than room temperature, wherein the thermal stress controlling layer reduces a film stress induced by formation of the piezoelectric body; and the supporting substrate is a diaphragm in which the liquid is ejected from the nozzle by changing a volume of the pressure chamber.

[0043] The present invention is also directed to the liquid ejection head wherein: the thermal stress controlling layer has a thermal expansion coefficient which is selected according to a first thermal expansion coefficient and a second thermal expansion coefficient, the first thermal expansion coefficient being a thermal expansion coefficient of piezoelectric body, the second thermal expansion coefficient being a thermal expansion coefficient of the supporting substrate.

[0044] The present invention is also directed to the liquid ejection head wherein: when the second thermal expansion coefficient is higher than the first thermal expansion coefficient, the thermal stress controlling layer has a thermal expansion coefficient which is lower than the second thermal expansion coefficient.

[0045] The present invention is also directed to the liquid ejection head wherein: when the second thermal expansion coefficient is higher than the first thermal expansion coefficient, the thermal stress controlling layer has a thermal expansion coefficient which is lower than the first thermal expansion coefficient.

[0046] The present invention is also directed to the liquid ejection head wherein: when the second thermal expansion coefficient is lower than the first thermal expansion coefficient, the thermal stress controlling layer has a thermal expansion coefficient which is higher than the second thermal expansion coefficient.

[0047] The present invention is also directed to the liquid ejection head wherein: when the second thermal expansion coefficient is lower than the first thermal expansion coefficient, the thermal stress controlling layer has a thermal expansion coefficient which is higher than the first thermal expansion coefficient.

[0048] The present invention is also directed to the liquid ejection head wherein the thermal stress controlling layer has a prescribed thickness required for reducing a thermal stress remaining in the piezoelectric body.

[0049] The present invention is also directed to the liquid ejection head wherein the thermal stress controlling layer also serves as an electrode for driving the piezoelectric body.

[0050] The present invention is also directed to the liquid ejection head wherein an electrode for driving the piezoelectric body is formed between the thermal stress controlling layer and the piezoelectric body.

[0051] The present invention is also directed to the liquid ejection head wherein a thickness of the supporting substrate is 30 μm or less.

[0052] The present invention is also directed to the liquid ejection head wherein a thickness of the piezoelectric body is 1 μm or greater.

[0053] The present invention is also directed to the liquid ejection head wherein the piezoelectric body is formed by an aerosol deposition method.

[0054] The present invention is also directed to the liquid ejection head wherein: the piezoelectric body formed by the aerosol deposition method is a PZT piezoelectric film; and a crystal a-axis length of the PZT piezoelectric film is in the range of 2.025 to 2.040 Angstroms.

[0055] The present invention is also directed to the liquid ejection head wherein the thermal stress controlling layer is formed by at least one of a sputtering method, a plating method, and an aerosol deposition method.

[0056] The present invention is also directed to the liquid ejection head wherein: the supporting substrate is made of stabilized zirconia; and the thermal stress controlling layer is made of platinum having a thickness of 2 to 5 μm.

[0057] The present invention is also directed to the liquid ejection head wherein: the supporting substrate is made of stabilized zirconia; and the thermal stress controlling layer is made of iridium having a thickness of 1 to 5 μm.

[0058] The present invention is also directed to the liquid ejection head wherein: the supporting substrate is made of silicon; and the thermal stress controlling layer is made of platinum having a thickness of 10 μm or less.

[0059] The present invention is also directed to the liquid ejection head wherein: the supporting substrate is made of silicon; and the thermal stress controlling layer is made of nickel having a thickness of 1 to 5 μm.

[0060] The present invention is also directed to the liquid ejection head wherein: the supporting substrate is made of silicon; and the thermal stress controlling layer is made of titanium oxide having a thickness of 2 to 5 μm.

[0061] According to the present invention, the liquid ejection head can achieve a high precision and a high-torque.

[0062] The present invention is directed to a method of manufacturing a piezoelectric actuator comprising the steps of: forming a thermal stress controlling layer on a supporting substrate; and forming a piezoelectric film by an aerosol deposition method in which an aerosol containing a powder of a piezoelectric material is sprayed onto the thermal stress controlling layer to accumulate the powder onto the thermal stress controlling layer, wherein the thermal stress controlling layer is formed in the step of forming the thermal stress controlling layer so as to have a thermal expansion coefficient and a thickness for reducing deformation of the supporting substrate due to thermal stress in the piezoelectric film.

[0063] According to the present invention, since a stress control layer is formed between the supporting substrate and the piezoelectric body formed directly on the supporting substrate, it is possible to reduce the film stress in the piezoelectric body formed on the supporting substrate, and hence, deformation of the supporting substrate can be suppressed.

BRIEF DESCRIPTION OF THE DRAWINGS

[0064] The nature of this invention, as well as other objects and advantages thereof, will be explained in the following with reference to the accompanying drawings, in which like reference characters designate the same or similar parts throughout the figures and wherein:

[0065] **FIG. 1** is a general schematic drawing of an inkjet recording apparatus according to an embodiment of the present invention;

[0066] **FIG. 2** is a plan view of the principal components in the peripheral area of a printing unit in the inkjet recording apparatus shown in **FIG. 1**;

[0067] **FIG. 3** is a schematic drawing showing a film formation device according to an aerosol deposition method;

[0068] **FIG. 4A** is a graph showing a relationship between the thickness of a piezoelectric body made of PZT, the displacement volume, and the generated pressure, and **FIG. 4B** is a graph showing a relationship between the thickness of a diaphragm, the displacement volume, and the generated pressure;

[0069] **FIG. 5** is a principal cross-sectional diagram of the piezoelectric actuator according to a first embodiment of the present invention;

[0070] **FIG. 6** is a graph showing a relationship between the film stress in the case in which a PZT piezoelectric film is formed on a zirconia substrate, and the thickness of the stress buffer layer made of platinum;

[0071] **FIG. 7** is a graph showing a relationship between the thermal expansion coefficient of the diaphragm (supporting substrate) and the film stress in the PZT piezoelectric film;

[0072] **FIG. 8** is a principal cross-sectional diagram of the piezoelectric actuator according to a second embodiment of the present invention;

[0073] **FIG. 9** is a graph showing a relationship between the film thickness of the stress buffer layer made of platinum and the amount of stress deformation in the silicon substrate, in the case in which a stress buffer layer is interposed between the silicon substrate and the PZT piezoelectric film;

[0074] **FIG. 10** is a principal cross-sectional diagram of the piezoelectric actuator according to a third embodiment of the present invention;

[0075] **FIG. 11** is a principal cross-sectional diagram of a liquid ejection head having a piezoelectric actuator;

[0076] **FIG. 12** is a principal cross-sectional diagram of a liquid ejection head; and

[0077] **FIG. 13A** is a diagram showing an ideal state in which there is no film stress in a piezoelectric body formed on a diaphragm so that there is no deformation of the diaphragm, and **FIG. 13B** is a diagram showing a state in which a compressive stress acts on the piezoelectric body and the diaphragm deforms unevenly due to the stress.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

General Composition of Ink-Jet Recording Apparatus

[0078] Firstly, a general composition of an inkjet recording apparatus having a liquid ejection head according to the present invention will be described below.

[0079] **FIG. 1** is a general schematic diagram showing general composition of the inkjet recording apparatus according to an embodiment of the present invention. As shown in **FIG. 1**, the inkjet recording apparatus **10** com-

prises: a printing unit **12** having a plurality of liquid ejection heads (hereinafter simply called "head") **12**K, **12**C, **12**M, and **12**Y for ink colors of black (K), cyan (C), magenta (M), and yellow (Y), respectively; an ink storing and loading unit **14** for storing inks of K, C, M and Y to be supplied to the heads **12**K, **12**C, **12**M, and **12**Y; a paper supply unit **18** for supplying a recording paper **16**; a decurling unit **20** for removing curl in the recording paper **16**; a suction belt conveyance unit **22** disposed facing the nozzle face (ink-droplet ejection face) of the printing unit **12**, for conveying the recording paper **16** while keeping the recording paper **16** flat; a print determination unit **24** for reading the printed result produced by the printing unit **12**; and a paper output unit **26** for outputting image-printed recording paper **16** (printed matter) to the exterior.

[**0080**] The recording paper **16** delivered from the paper supply unit **18** retains curl due to having been loaded in the magazine. In order to remove the curl, heat is applied to the recording paper **16** in the decurling unit **20** by a heating drum **30** in the direction opposite from the curl direction in the magazine.

[**0081**] In the case of the configuration in which roll paper is used, a cutter (first cutter) **28** is provided as shown in **FIG. 1**, and the continuous paper is cut into a desired size by the cutter **28**. The cutter **28** has a stationary blade **28**A, of which length is not less than the width of the conveyor pathway of the recording paper **16**, and a round blade **28**B, which moves along the stationary blade **28**A. The stationary blade **28**A is disposed on the reverse side of the printed surface of the recording paper **16**, and the round blade **28**B is disposed on the printed surface side across the conveyor pathway. When cut papers are used, the cutter **28** is not required.

[**0082**] The decurled and cut recording paper **16** is delivered to the suction belt conveyance unit **22**. The suction belt conveyance unit **22** has a configuration in which an endless belt **33** is set around rollers **31** and **32** so that the portion of the endless belt **33** facing at least the nozzle face of the printing unit **12** and the sensor face of the print determination unit **24** forms a horizontal plane (flat plane).

[**0083**] The belt **33** has a width that is greater than the width of the recording paper **16**, and a plurality of suction apertures (not shown) are formed on the belt surface. A suction chamber **34** is disposed in a position facing the sensor surface of the print determination unit **24** and the nozzle surface of the printing unit **12** on the interior side of the belt **33**, which is set around the rollers **31** and **32**, as shown in **FIG. 1**. The suction chamber **34** provides suction with a fan **35** to generate a negative pressure, and the recording paper **16** on the belt **33** is held by suction.

[**0084**] The belt **33** is driven in the clockwise direction in **FIG. 1** by the motive force of a motor (not shown) being transmitted to at least one of the rollers **31** and **32**, which the belt **33** is set around, and the recording paper **16** held on the belt **33** is conveyed from left to right in **FIG. 1**.

[**0085**] Since ink adheres to the belt **33** when a marginless print job or the like is performed, a belt-cleaning unit **36** is disposed in a predetermined position (a suitable position outside the printing area) on the exterior side of the belt **33**.

[**0086**] A heating fan **40** is disposed on the upstream side of the printing unit **12** in the conveyance pathway formed by the suction belt conveyance unit **22**. The heating fan **40** blows heated air onto the recording paper **16** to heat the recording paper **16** immediately before printing so that the ink deposited on the recording paper **16** dries more easily.

[**0087**] The printing unit **12** is a so-called "full line head" in which a line head having a is length corresponding to the maximum paper width is arranged in a direction (main scanning direction) that is perpendicular to the paper feed direction (see **FIG. 2**). Each of the heads **12**K, **12**C, **12**M, and **12**Y is constituted by a line head, in which a plurality of ink ejection ports (nozzles) are arranged along a length that exceeds at least one side of the maximum-size recording paper **16** intended for use in the inkjet recording apparatus **10**, as shown in **FIG. 2**.

[**0088**] The heads **12**K, **12**C, **12**M, and **12**Y are arranged in the order of black (K), cyan (C), magenta (M), and yellow (Y) from the upstream side, along the feed direction of the recording paper **16**. A color image can be formed on the recording paper **16** by ejecting the inks from the heads **12**K, **12**C, **12**M, and **12**Y, respectively, onto the recording paper **16** while conveying the recording paper **16**.

[**0089**] The print determination unit **24** has a line sensor for capturing an image of the ink-droplet deposition result of the printing unit **12**, and functions as a device to check for ejection defects such as clogs of the nozzles in the printing unit **12** from the ink-droplet deposition results evaluated by the line sensor.

[**0090**] A post-drying unit **42** is disposed following the print determination unit **24**. The post-drying unit **42** is a device to dry the printed image surface, and includes a heating fan, for example. It is preferable to avoid contact with the printed surface until the printed ink dries, and a device that blows heated air onto the printed surface is preferable.

[**0091**] A heating/pressurizing unit **44** is disposed following the post-drying unit **42**. The heating/pressurizing unit **44** is a device to control the glossiness of the image surface, and the image surface is pressed with a pressure roller **45** having a predetermined uneven surface shape while the image surface is heated, and the uneven shape is transferred to the image surface.

[**0092**] The printed matter generated in this manner is cut to a prescribed size by the cutter **28** and then output from the paper output unit **26**. The target print (i.e., the result of printing the target image) and the test print are preferably output separately. In the inkjet recording apparatus **10**, a sorting device (not shown) is provided for switching the outputting pathways in order to sort the printed matter with the target print and the printed matter with the test print, and to send them to paper output units **26**A and **26**B, respectively. When the target print and the test print are simultaneously formed in parallel on the same large sheet of paper, the test print portion is cut and separated by a cutter (second cutter) **48**.

Method for Forming Film According to Aerosol Deposition Method

[**0093**] Next, a method for forming film according to an aerosol deposition method as used in the manufacture of a piezoelectric actuator according to the present invention will be described below.

[0094] **FIG. 3** is a schematic drawing showing a film formation device according to the aerosol deposition method. This film formation device has an aerosol generating chamber **52** in which a raw material powder **51** is provided. Herein, the term "aerosol" includes fine particles of a solid or liquid which are suspended in a gas.

[0095] A carrier gas input section **53**, an aerosol output section **54**, and a vibrating unit **55** are attached to the aerosol generating chamber **52**. When a gas such as nitrogen gas (N_2) is introduced via the carrier gas input section **53**, the raw material powder is blown and lifted in the aerosol generating chamber **52**, thereby generating an aerosol. In this case, if a vibration is applied to the aerosol generating chamber **52** by means of the vibrating unit **55**, then the raw material powder is churned up, thereby generating an aerosol efficiently. Thus, the generated aerosol is channeled through the aerosol output section **54** to a film formation chamber **56**.

[0096] An exhaust tube **57**, a nozzle **58**, and a movable stage **59** are provided in the film formation chamber **56**. The exhaust tube **57** is connected to a vacuum pump, and evacuates the interior of the film formation chamber **56**. After the aerosol is generated in the aerosol generating chamber **52** and is conducted to the film formation chamber **56** via the aerosol output section **54**, the aerosol is sprayed from the nozzle **58** onto a supporting substrate **50**. Hence, the raw material powder collides with the supporting substrate **50**, and builds up thereon. The supporting substrate **50** is mounted on the movable stage **59** that is capable of three-dimensional movement, and hence the relative positions of the supporting substrate **50** and the nozzle **58** can be adjusted by controlling the movable stage **59**.

Target Thickness of Piezoelectric Body and Supporting Substrate

[0097] In order to achieve a liquid ejection head of high density, the dimensions of the piezoelectric body are set to 300 μm square, and the dimensions of the supporting substrate (diaphragm) are set to 500 μm square.

[0098] **FIG. 4A** is a graph showing a relationship between the thickness of a piezoelectric body made of lead zirconate titanate ($Pb(ZrTi)O_3$) (PZT) under the aforementioned conditions, the displacement volume, and the generated pressure. **FIG. 4B** is a graph showing a relationship between the thickness of a diaphragm, the displacement volume, and generated pressure.

[0099] As shown in **FIG. 4A**, if the liquid droplet size (target volume) of the liquid ejection head is set to x picoliters (pl) and the target pressure is set to y Megapascal (MPa), then the thickness of a PZT film is 10 μm to satisfy both the target volume and the target pressure.

[0100] Similarly, as shown in **FIG. 4B**, when the target volume is set to x (pl), and the target pressure is set to y (MPa), then the thickness of a diaphragm is 15 μm to satisfy both the target volume and the target pressure.

[0101] When forming PZT directly onto a diaphragm, a film can only be formed to a thickness of approximately 3 μm by the sputtering method. Therefore, it is preferably to use the aerosol deposition method in order to form the PZT film of 10 μm as described above.

Structure of Piezoelectric Actuator

[0102] As described above, when a PZT piezoelectric body having a thickness of 10 μm is formed by the aerosol deposition method on a diaphragm having a thickness of 15 μm, then a strong compressive stress acts on the actual PZT piezoelectric film having a fine structure, while thermal stress also acts due to the difference between the thermal expansion coefficients of the PZT piezoelectric film and the diaphragm, and hence the diaphragm undergoes stress deformation due to the stress in the PZT piezoelectric film. Therefore, the present invention attempts to reduce the film stress in the PZT piezoelectric film (in other words, to suppress stress deformation in the diaphragm), by interposing a thermal stress controlling layer between the diaphragm and the PZT piezoelectric film along with altering the thermal expansion coefficient and thickness of this thermal stress controlling layer.

First Embodiment: Case in which Thermal Expansion Coefficient of Diaphragm is Higher than that of Piezoelectric Body

[0103] In the case in which the thermal expansion coefficient of the diaphragm is higher than that of the piezoelectric body, then a thin film made of a material having a lower thermal expansion coefficient than the diaphragm (preferably, a thermal stress controlling layer (stress buffer layer) made of a material having a lower thermal expansion coefficient than the piezoelectric body) is formed previously on the diaphragm.

[0104] **FIG. 5** is a principal cross-sectional diagram of a piezoelectric actuator **60** according to a first embodiment. As shown in **FIG. 5**, the piezoelectric actuator **60** comprises: a stabilized zirconia substrate **62** (thermal expansion coefficient: 9.9×10^{-6}/° C.) as the diaphragm; and a PZT piezoelectric film **64** (thermal expansion coefficient: 9.5×10^{-6}/° C.) as the piezoelectric body. The stabilized zirconia substrate (hereinafter referred to as simply "zirconia substrate") **62** can be made of calcia (CaO) stabilized zirconia (ZrO_2) or magnesia (MgO) stabilized zirconia, more preferably yttria (Y_2O_3) stabilized zirconia. A stress buffer layer **66** made of platinum (Pt) (thermal expansion coefficient: 8.8×10^{-6}/° C.) which has a lower thermal expansion coefficient than PZT is formed between the zirconia substrate **62** and the PZT piezoelectric film **64**.

[0105] The stress buffer layer **66** is formed on the zirconia substrate **62** by the sputtering method, the plating method, or the aerosol deposition method. The PZT piezoelectric film **64** is formed on the stress buffer layer **66** by the aerosol deposition method. The temperature during film formation by the aerosol deposition method is approximately 600° C.

[0106] **FIG. 6** is a graph showing the relationship between the film stress in the case in which a PZT piezoelectric film **64** is formed on a zirconia substrate **62**, and the thickness of the stress buffer layer **66**. On the graph in **FIG. 6**, the target film stress (40 MPa) is the target value for the film stress at which the deformation of the substrate can be kept to 10 μm (corresponding to the thickness of the adhesive) or less.

[0107] As shown on the graph in **FIG. 6**, when the film thickness of the stress buffer layer **66** is zero (in other words, when no stress buffer layer **66** is formed), then the film stress (compressive stress) in the PZT piezoelectric film **64**

becomes a maximum. As the film thickness of the stress buffer layer **66** becomes greater, then the state approaches that of a film formed on a platinum substrate, and therefore, it is found that the actual film stress approaches a film stress corresponding to an ideal platinum substrate.

[**0108**] According to the graph shown in **FIG. 6**, it is found that the stress reaches the target film stress (−40 MPa) when the film thickness of the stress buffer layer **66** is 2 μm.

[**0109**] On the other hand, **FIG. 7** is a graph showing a relationship between the thermal expansion coefficient of the diaphragm (supporting substrate) and the film stress in the PZT piezoelectric film.

[**0110**] According to the graph in **FIG. 7**, when the thermal expansion coefficient of the supporting substrate is approximately 8×10^{-6}/° C., then the film stress in the PZT piezoelectric film is zero. In this case, the thermal expansion coefficient of the supporting substrate (approximately, 8×10^{-6}/° C.) is smaller than the thermal expansion coefficient of the PZT piezoelectric film (approximately, 9.5×10^{-6}/° C.), and hence it does not match the thermal expansion coefficient of the PZT piezoelectric film. This is because a large compressive stress acts on the PZT piezoelectric film which has a fine structure formed by the aerosol deposition method, and the thermal expansion coefficient of the supporting substrate which enables the film stress in the PZT piezoelectric film to be reduced to zero is a value (approximately 8×10^{-6}/° C.) which allows the aforementioned compressive stress to be cancelled out by thermal stress. This value is smaller than the thermal expansion coefficient of the PZT piezoelectric film.

[**0111**] On the graph in **FIG. 7**, when a supporting substrate has a thermal expansion coefficient of 8.8×10^{-6}/° C. corresponding to that of platinum, the predicted film stress is −60 MPa. This predicted film stress virtually coincides with experimental results of a case in which a platinum stress buffer layer **66** is formed on a zirconia substrate **62**.

[**0112**] As described above, it has been confirmed that, when the thermal expansion coefficient of the diaphragm is greater than that of the piezoelectric body, a thin film (stress buffer layer) is formed between the diaphragm and the piezoelectric body so as to have a thermal expansion coefficient which is lower than the thermal expansion coefficient of the piezoelectric body, and the thickness of this thin film is controlled, thereby being able to relieve the true stress in the piezoelectric film by means of thermal stress.

[**0113**] As is evident from **FIG. 6**, if a thickness of platinum is 2 μm, then the tensile stress caused by thermal stress is not sufficient. Therefore, the compressive stress in the PZT piezoelectric film is not cancelled out completely. If the PZT piezoelectric film **64** is formed on the zirconia substrate **62**, then it is possible to in cancel out film stress effectively by introducing a stress buffer layer which has a thermal expansion coefficient lower than the coefficient (8.8×10^{-6}/° C.) of thermal expansion of platinum. For example, a film of iridium (Ir) having a thickness of 1 to 5 μm (thermal expansion coefficient: 6.5×10^{-6}/° C.) is effective as a stress buffer layer.

Second Embodiment: Case in which Thermal Expansion Coefficient of Diaphragm is Lower than that of Piezoelectric Body

[**0114**] In the case in which the thermal expansion coefficient of the diaphragm is lower than that of the piezoelectric body, a thin film made of a material having a higher thermal expansion coefficient than the diaphragm (preferably, a thermal stress controlling layer (stress buffer layer) made of a material having a higher thermal expansion coefficient than the piezoelectric body) is formed previously on the diaphragm.

[**0115**] **FIG. 8** is a principal cross-sectional diagram of a piezoelectric actuator **70** according to a second embodiment. As shown in **FIG. 8**, the piezoelectric actuator **70** comprises a silicon (Si) substrate **72** (thermal expansion coefficient: 3.5×10^{-6}/° C.) as the diaphragm, and a PZT piezoelectric film **64** (thermal expansion coefficient: 9.5×10^{-6}/° C.) as the piezoelectric body. A stress buffer layer **74** made of platinum (thermal expansion coefficient: 8.8×10^{-6}/° C.) is formed between the silicon substrate **72** and the PZT piezoelectric film **64**, which has a higher thermal expansion coefficient than silicon. Since the method for forming the stress buffer layer **74** and the PZT piezoelectric film **64** on the silicon substrate **72** is similar to that of the first embodiment shown in **FIG. 5**, the description thereof is omitted here.

[**0116**] **FIG. 9** is a graph showing a relationship between the film thickness of the stress buffer layer **74** and the amount of stress deformation in the silicon substrate **72**, in the case in which a stress buffer layer **74** is interposed between the silicon substrate **72** and the PZT piezoelectric film **64**.

[**0117**] When a platinum stress buffer layer **74** is not formed, there is a strong tensile stress due to the thermal stress caused by a difference between the thermal expansion coefficient of the silicon substrate **72** and the thermal expansion coefficient of the PZT piezoelectric film **64**, and then the amount of deformation is large. However, as the thickness of the stress buffer layer **74** increases, so the thermal expansion coefficient of the stress buffer layer **74** becomes dominant.

[**0118**] As shown in the graph of **FIG. 9**, it is found that, when the thickness of platinum stress buffer layer **74** reaches approximately 9 μm, the film stress of the PZT piezoelectric film **64** is cancelled out, and then the deformation by the film stress becomes zero.

[**0119**] The thermal expansion coefficient of platinum (8.8×10^{-6}/° C.) is higher than the thermal expansion coefficient of silicon (3.5×10^{-6}/° C.), but lower than the thermal expansion coefficient of PZT (9.5×10^{-6}/° C.). Therefore, although a thermal stress in the compressive direction does not act on the PZT piezoelectric film **64** from the platinum stress buffer layer **74**, the thermal stress in the tensile direction can be relieved effectively, in comparison with the case in which the PZT piezoelectric film **64** is formed directly onto the silicon substrate **72**. As shown in **FIG. 7**, a strong compressive stress acts essentially on the PZT piezoelectric film **64**. Therefore, when the thermal stress in the tensile direction is relieved by means of the platinum stress buffer layer **74**, the compressive stress in the PZT piezoelectric film **64** can be cancelled out by means of this relieved thermal stress (tensile stress).

[**0120**] Furthermore, it is expected that, when a stress buffer layer constituted by a material which has a higher thermal expansion coefficient than platinum, more preferably a material having a higher thermal expansion coefficient than PZT (for example, nickel (Ni) having a thermal expansion coefficient of 13×10^{-6}/° C.), is introduced instead

of the platinum stress buffer layer **74**, the stress in the PZT piezoelectric film **64** can be cancelled out by a stress buffer layer which is thinner than a platinum stress buffer layer **74**. More specifically, in the case in which the thermal expansion coefficient of the diaphragm is lower than that of the piezoelectric body, a stress buffer layer made of a material which has a higher thermal expansion coefficient than the piezoelectric body is formed between the diaphragm and the piezoelectric body, and the thickness of this stress buffer layer is controlled, thereby being able to cancel out the true stress in the piezoelectric film and the thermal stress to each other.

Third Embodiment: Case of Diaphragm+Stress Buffer Layer+Electrode+PZT Piezoelectric Body (i.e., a Plurality of Stress Buffer Layers)

[0121] The platinum stress buffer layers **66** and **74** shown in **FIG. 5** and **FIG. 8** also serve as an electrode (lower electrode) for driving the PZT piezoelectric film **64**, but the stress buffer layer and the electrode may be separately functionally.

[0122] **FIG. 10** is a principal cross-sectional diagram of a piezoelectric actuator **80** according to a third embodiment. As shown in **FIG. 10**, the piezoelectric actuator **80** comprises a silicon substrate **72** (thermal expansion coefficient: 3.5×10^{-6}/° C.) as the diaphragm, and a PZT piezoelectric film **64** (thermal expansion coefficient: 9.5×10^{-6}/° C.) as the piezoelectric body. A stress buffer layer **82** made of nickel (thermal expansion coefficient: 13×10^{-6}/° C.) and a platinum electrode **84** (thermal expansion coefficient: 8.8×10^{-6}/° C.) are formed between the silicon substrate **72** and the PZT piezoelectric film **64**. The stress buffer layer **82** has a higher thermal expansion coefficient than PZT, and the platinum electrode **84** functions as the electrode. For example, the stress buffer layer **82** and the platinum electrode **84** are formed by the sputtering method, and the PZT piezoelectric film **64** is formed by the aerosol deposition method.

[0123] In this case, it is found that, when the film thickness of the platinum electrode **84** is in the region of 1 μm or less, the stress buffer layer **82** is dominant in controlling stress. Furthermore, it is also confirmed that there are no problems with the electrode functions in a platinum electrode **84** of 1 μm or less.

[0124] Titanium oxide (TiO_2) (thermal expansion coefficient: 10 to 15×10^{-6}/° C.) is another possible candidate for the stress buffer layer besides the nickel film described above, and any other material may be used for satisfying the prescribed conditions according to the thermal expansion coefficient.

Manufacturing of Piezoelectric Actuator having Aforementioned Composition and Inspection of Stress Deformation

[0125] **FIG. 11** is a principal cross-sectional diagram of a liquid ejection head **90** having a piezoelectric actuator of the aforementioned composition.

[0126] As shown in **FIG. 11**, the liquid ejection head **90** comprises: a lower electrode **92** as a stress buffer layer, which is formed on a silicon substrate **91** by the sputtering method; a PZT piezoelectric film **93** (300 μm square) which is patterned onto the lower electrode **92** by the aerosol deposition method; an upper electrode **94** which is formed on top of the PZT piezoelectric film **93**; and a silicon diaphragm **95** which is formed on the opposite side to the PZT piezoelectric film **93** by etching. The spaces formed by etching the silicon diaphragm **95** are applied as a plurality of pressure chambers **96** filled with a liquid such as an ink, and the silicon substrate **91** surrounding the pressure chambers **96** is applied as the pressure chamber walls. In this case, the thickness of the silicon diaphragm **95** was set to 15 μm.

[0127] In this inspection, the PZT piezoelectric film **93** was poled by applying a DC electric field of 3 kV/mm between the lower and upper electrodes **92** and **94** of the PZT piezoelectric film **93**. Then, the silicon diaphragm **95** was driven and displaced by applying a DC pulse electric field of approximately 1 kV/mm between the lower and upper electrodes **92** and **94**, and a laser beam was directed onto the lower surface of the silicon diaphragm **95**, thereby evaluating the operation of the piezoelectric actuator.

[0128] It was confirmed that, when no stress buffer layer was introduced, the silicon diaphragm **95** was deformed by stress in the region corresponding to the PZT piezoelectric film **93**, so that there was variation in the amount of displacement. On the other hand, it was confirmed that, when a stress buffer layer was introduced, the amount of displacement was stabilized between ±10%.

Quantification of Film Stress

[0129] The crystal a-axis length was evaluated by X-ray diffraction (XRD) in order to quantify the film stress in the PZT piezoelectric film (aerosol deposition film).

[0130] First, when the PZT micro-particles forming the starting material of the aerosol deposition film were evaluated by XRD in order to ascertain the stress-free state, the a-axis length was 2.034 Angstroms (Å). Next, when a bulk calcined object obtained by calcining PZT micro-particles at 1250° C. was evaluated, the a-axis length was 2.030 Å. Consequently, the a-axis length of the PZT in a stress-free state was set to be between approximately 2.025 and 2.040 Å. In other words, the average between the a-axis length (2.034 Å) of the PZT micro-particles and the a-axis length (2.030 Å) of the bulk calcined object), namely, 2.032±0.007 Å, is taken to be PZT in a stress-free state. Herein, the upper and lower limit values of the range 2.025 to 2.040 Å described above are the values at which the amount of deformation of the diaphragm becomes ±10 μm, due to the film stress of the PZT piezoelectric film. Furthermore, 10 μm is the thickness of the adhesive used to bond the diaphragm to the ink chamber walls and the like.

[0131] In the case of introducing no stress buffer layer, the a-axis length of the PZT piezoelectric film formed by the aerosol deposition method became 2.055 Å. On the other hand, in the case of an embodiment in which the film stress was reduced to 10%, it was confirmed that the a-axis length changed to 2.033 Å.

Structure of Liquid Ejection Head

[0132] **FIG. 12** is a principal cross-sectional diagram of a liquid ejection head **90'**. In **FIG. 12**, identical reference numerals denote parts that are common to **FIG. 11**, and description thereof is omitted here.

[0133] As shown in **FIG. 12**, the liquid ejection head **90'** is formed by bonding a nozzle plate **97** onto the lower surface of the silicon substrate **91** shown in **FIG. 11**.

[0134] A liquid (ink) is supplied via a liquid flow channel (not shown) to the pressure chambers **96**. Therefore, when a silicon diaphragm **95** is displacing by driving PZT piezoelectric films **93**, the liquid ejection head **90'** ejects ink of a prescribed liquid droplet size from nozzles **98** formed in the nozzle plate **97**.

[0135] As described above, the piezoelectric actuator according to the present invention is explained with reference to the case in which it is used as an actuator of a liquid ejection head, but it may also be used as an actuator in other devices. Furthermore, the liquid ejection head according to the present invention is used as a line-type inkjet head which ejects ink onto recording paper, but the present invention is not limited to those. It may also be applied to a shuttle-type head which moves back and forth reciprocally in a direction perpendicular to the conveyance direction of the print medium. Moreover, the liquid ejection head according to the present invention may be used as an image forming head which sprays a treatment liquid or water onto a recording medium, or may be used as a liquid ejection head for forming an image recording medium by spraying a coating liquid onto a base material.

[0136] It should be understood, however, that there is no intention to limit the invention to the specific forms disclosed, but on the contrary, the invention is to cover all modifications, alternate constructions and equivalents falling within the spirit and scope of the invention as expressed in the appended claims.

What is claimed is:

1. A piezoelectric actuator, comprising:

a supporting substrate;

a thermal stress controlling layer which is formed on the supporting substrate; and

a piezoelectric body which is formed as a film onto the thermal stress controlling layer on the supporting substrate at a higher temperature than room temperature,

wherein the thermal stress controlling layer reduces a film stress induced by formation of the piezoelectric body.

2. The piezoelectric-actuator as defined in claim 1, wherein:

the thermal stress controlling layer has a thermal expansion coefficient which is selected according to a first thermal expansion coefficient and a second thermal expansion coefficient, the first thermal expansion coefficient being a thermal expansion coefficient of piezoelectric body, the second thermal expansion coefficient being a thermal expansion coefficient of the supporting substrate.

3. The piezoelectric actuator as defined in claim 2, wherein:

when the second thermal expansion coefficient is higher than the first thermal expansion coefficient, the thermal stress controlling layer has a thermal expansion coefficient which is lower than the second thermal expansion coefficient.

4. The piezoelectric actuator as defined in claim 2, wherein:

when the second thermal expansion coefficient is higher than the first thermal expansion coefficient, the thermal stress controlling layer has a thermal expansion coefficient which is lower than the first thermal expansion coefficient.

5. The piezoelectric actuator as defined in claim 2, wherein:

when the second thermal expansion coefficient is lower than the first thermal expansion coefficient, the thermal stress controlling layer has a thermal expansion coefficient which is higher than the second thermal expansion coefficient.

6. The piezoelectric actuator as defined in claim 2, wherein:

when the second thermal expansion coefficient is lower than the first thermal expansion coefficient, the thermal stress controlling layer has a thermal expansion coefficient which is higher than the first thermal expansion coefficient.

7. The piezoelectric actuator as defined in claim 1, wherein the thermal stress controlling layer has a prescribed thickness required for reducing a thermal stress remaining in the piezoelectric body.

8. The piezoelectric actuator as defined in claim 1, wherein the thermal stress controlling layer also serves as an electrode for driving the piezoelectric body.

9. The piezoelectric actuator as defined in claim 1, wherein an electrode which drives the piezoelectric body is formed between the thermal stress controlling layer and the piezoelectric body.

10. The piezoelectric actuator as defined in claim 1, wherein a thickness of the supporting substrate is 30 μm or less.

11. The piezoelectric actuator as defined in claim 1, wherein a thickness of the piezoelectric body is 1 μm or greater.

12. The piezoelectric actuator as defined in claim 1, wherein the piezoelectric body is formed by an aerosol deposition method.

13. The piezoelectric actuator as defined in claim 12, wherein:

the piezoelectric body formed by the aerosol deposition method is a PZT piezoelectric film; and

a crystal a-axis length of the PZT piezoelectric film is in the range of 2.025 to 2.040 Angstroms.

14. The piezoelectric actuator as defined in claim 1, wherein the thermal stress controlling layer is formed by at least one of a sputtering method, a plating method, and an aerosol deposition method.

15. The piezoelectric actuator as defined in claim 1, wherein:

the supporting substrate is made of stabilized zirconia; and

the thermal stress controlling layer is made of platinum having a thickness of 2 to 5 μm.

16. The piezoelectric actuator as defined in claim 1, wherein:

the supporting substrate is made of stabilized zirconia; and

the thermal stress controlling layer is made of iridium having a thickness of 1 to 5 μm.

17. The piezoelectric actuator as defined in claim 1, wherein:

the supporting substrate is made of silicon; and

the thermal stress controlling layer is made of platinum having a thickness of 10 μm or less.

18. The piezoelectric actuator as defined in claim 1, wherein:

the supporting substrate is made of silicon; and

the thermal stress controlling layer is made of nickel having a thickness of 1 to 5 μm.

19. The piezoelectric actuator as defined in claim 1, wherein:

the supporting substrate is made of silicon; and

the thermal stress controlling layer is made of titanium oxide having a thickness of 2 to 5 μm.

20. A liquid ejection head, comprising:

a pressure chamber which fills with a liquid;

a nozzle which ejects the liquid from the pressure chamber; and

a piezoelectric actuator which comprises a supporting substrate; a thermal stress controlling layer which is formed on the supporting substrate; and a piezoelectric body which is formed as a film onto the thermal stress controlling layer on the supporting substrate at a higher temperature than room temperature,

wherein the thermal stress controlling layer reduces a film stress induced by formation of the piezoelectric body; and

the supporting substrate is a diaphragm in which the liquid is ejected from the nozzle by changing a volume of the pressure chamber.

21. The liquid ejection head as defined in claim 20, wherein:

the thermal stress controlling layer has a thermal expansion coefficient which is selected according to a first thermal expansion coefficient and a second thermal expansion coefficient, the first thermal expansion coefficient being a thermal expansion coefficient of piezoelectric body, the second thermal expansion coefficient being a thermal expansion coefficient of the supporting substrate.

22. The liquid ejection head as defined in claim 21, wherein:

when the second thermal expansion coefficient is higher than the first thermal expansion coefficient, the thermal stress controlling layer has a thermal expansion coefficient which is lower than the second thermal expansion coefficient.

23. The liquid ejection head as defined in claim 21, wherein:

when the second thermal expansion coefficient is higher than the first thermal expansion coefficient, the thermal stress controlling layer has a thermal expansion coefficient which is lower than the first thermal expansion coefficient.

24. The liquid ejection head as defined in claim 21, wherein:

when the second thermal expansion coefficient is lower than the first thermal expansion coefficient, the thermal stress controlling layer has a thermal expansion coefficient which is higher than the second thermal expansion coefficient.

25. The liquid ejection head as defined in claim 21, wherein:

when the second thermal expansion coefficient is lower than the first thermal expansion coefficient, the thermal stress controlling layer has a thermal expansion coefficient which is higher than the first thermal expansion coefficient.

26. The liquid ejection head as defined in claim 20, wherein the thermal stress controlling layer has a prescribed thickness required for reducing a thermal stress remaining in the piezoelectric body.

27. The liquid ejection head as defined in claim 20, wherein the thermal stress controlling layer also serves as an electrode for driving the piezoelectric body.

28. The liquid ejection head as defined in claim 20, wherein an electrode for driving the piezoelectric body is formed between the thermal stress controlling layer and the piezoelectric body.

29. The liquid ejection head as defined in claim 20, wherein a thickness of the supporting substrate is 30 μm or less.

30. The liquid ejection head as defined in claim 20, wherein a thickness of the piezoelectric body is 1 μm or greater.

31. The liquid ejection head as defined in claim 20, wherein the piezoelectric body is formed by an aerosol deposition method.

32. The liquid ejection head as defined in claim 31, wherein:

the piezoelectric body formed by the aerosol deposition method is a PZT piezoelectric film; and

a crystal a-axis length of the PZT piezoelectric film is in the range of 2.025 to 2.040 Angstroms.

33. The liquid ejection head as defined in claim 20, wherein the thermal stress controlling layer is formed by at least one of a sputtering method, a plating method, and an aerosol deposition method.

34. The liquid ejection head as defined in claim 20, wherein:

the supporting substrate is made of stabilized zirconia; and

the thermal stress controlling layer is made of platinum having a thickness of 2 to 5 μm.

35. The liquid ejection head as defined in claim 20, wherein:

the supporting substrate is made of stabilized zirconia; and

the thermal stress controlling layer is made of iridium having a thickness of 1 to 5 μm.

36. The liquid ejection head as defined in claim 20, wherein:

the supporting substrate is made of silicon; and

the thermal stress controlling layer is made of platinum having a thickness of 10 μm or less.

37. The liquid ejection head as defined in claim 20, wherein:

the supporting substrate is made of silicon; and

the thermal stress controlling layer is made of nickel having a thickness of 1 to 5 μm.

38. The liquid ejection head as defined in claim 20, wherein:

the supporting substrate is made of silicon; and

the thermal stress controlling layer is made of titanium oxide having a thickness of 2 to 5 μm.

39. A method of manufacturing a piezoelectric actuator, comprising the steps of:

forming a thermal stress controlling layer on a supporting substrate; and

forming a piezoelectric film by an aerosol deposition method in which an aerosol containing a powder of a piezoelectric material is sprayed onto the thermal stress controlling layer to accumulate the powder onto the thermal stress controlling layer,

wherein the thermal stress controlling layer is formed in the step of forming the thermal stress controlling layer so as to have a thermal expansion coefficient and a thickness for reducing deformation of the supporting substrate due to thermal stress in the piezoelectric film.

* * * * *