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VIBRATOR AND VIBRATION WAVE MOTOR

Abstract

A vibrator includes an electromechanical transducer which is a piezoelectric ceramic made of sodium-potassium niobate metal oxides and whose temperature characteristics of a relative permittivity is 500 [ppm/° C.] or less in absolute value in a temperature range from −40° C. to 170° C., wherein excitation of the electromechanical transducer produces a vibration wave. Another vibrator includes an electromechanical transducer which is a piezoelectric ceramic made of sodium-potassium niobate metal oxides and whose temperature characteristics of a relative permittivity is 390 [ppm/° C.] or less in absolute value in a temperature range from 0° C. to 60° C., wherein excitation of the electromechanical transducer produces a vibration wave.

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Background/Summary

CLAIM OF PRIORITY [0001] The present application is a Continuation Application of U.S. patent application Ser. No. 17/927,195, filed Nov. 22, 2022, which is a National Stage Entry of PCT/JP2021/011795, filed Mar. 22, 2021, which claims priority from Japanese patent application JP 2020-97583 filed on Jun. 4, 2020, the contents of which are hereby incorporated by reference into this application.

BACKGROUND
[0002] The disclosure relates to a vibrator and a vibration wave motor.
[0003] As disclosed in JP 01-017354 B2, a vibration wave motor produces a traveling vibration wave (abbreviated as a traveling wave below) on a driving surface of an elastic body by using expansion and contraction of a piezoelectric body, this traveling wave causes an elliptical motion on the driving surface, and a mover placed in pressure contact with a crest of the elliptical motion is driven. However, JP 01-017354 B2 does not take into account a decrease in driving performance caused by a material of the piezoelectric body.
SUMMARY
[0004] A vibrator of a first disclosure comprises an electromechanical transducer which is a piezoelectric ceramic made of sodium-potassium niobate metal oxides and whose temperature characteristics of a relative permittivity is 500 [ppm/° C.] or less in absolute value in a temperature range from −40° C. to 170° C., wherein excitation of the electromechanical transducer produces a vibration wave.
[0005] A vibrator of a second disclosure comprises an electromechanical transducer which is a piezoelectric ceramic made of sodium-potassium niobate metal oxides and whose temperature characteristics of a relative permittivity is 390 [ppm/° C.] or less in absolute value in a temperature range from 0° C. to 60° C., wherein excitation of the electromechanical transducer produces a vibration wave.
[0006] A vibration wave motor of a third disclosure comprises: the vibrator according to any one of the first and second disclosure; and a relative motion member which includes a sliding surface placed in pressure contact with a driving surface of the vibrator, and is caused to make a relative motion by the vibration wave.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
[0007] FIG. **1** is a cross-sectional view illustrating a vibration wave motor according to embodiment 1.

[0008] FIG. **2** is a perspective view illustrating that part of a vibrator and a mover are cut out.
[0009] FIG. **3** is a block diagram illustrating a driving device of a vibration wave motor according to embodiment 1.
[0010] FIG. **4** is an explanatory view illustrating the piezoelectric body according to embodiment 1.
[0011] FIG. **5** is an explanatory view illustrating the vibrator according to embodiment 1.
[0012] FIG. **6** is a table illustrating constants (A to E), an electromechanical coupling factor, a relative permittivity, a piezoelectric constant, and temperature characteristics of the relative permittivity (change percentage) of chemical formula (1) of each material.
[0013] FIG. **7** is a view of temperature characteristics of a relative permittivity.
[0014] FIG. **8**A**1** is a graph illustrating temperature characteristics of electrostatic capacitances of materials α and β of the piezoelectric body according to embodiment 1 (part **1**).
[0015] FIG. **8**A**2** is a graph illustrating temperature characteristics of electrostatic capacitances of materials α and β of the piezoelectric body according to embodiment 1 (part **2**).
[0016] FIG. **8**B is a graph illustrating temperature characteristics of an electrostatic capacitance of the material γ of the piezoelectric body **11** according to embodiment 1.
[0017] FIG. **9**A**1** is a graph illustrating temperature characteristics of electrostatic capacitances of the vibrator in a case where the materials α and β are used (part **1**).
[0018] FIG. **9**A**2** is a graph illustrating temperature characteristics of electrostatic capacitances of the vibrator in a case where the materials α and β are used (part **2**).
[0019] FIG. **9**B is a graph illustrating temperature characteristics of an electrostatic capacitance of the vibrator **10** according to embodiment 1 in a case where the material γ is used.
[0020] FIG. **10**A is a graph illustrating a measured consumption current at each temperature for the vibration wave motor according to embodiment 1 and a vibration wave motor which is a PZT-mounted product (part **1**).
[0021] FIG. **10**B is a graph illustrating a measured consumption current at each temperature for the vibration wave motor according to embodiment 1 and a vibration wave motor which is a PZT-mounted product (part **2**).
[0022] FIG. **11** is an explanatory view illustrating an equivalent circuit of the vibrator of the vibration wave motor.
[0023] FIG. **12** is a table showing a lowest voltage (referred to a drivable voltage below) of a drive signal which can drive the vibration wave motor according to embodiment 1.
[0024] FIG. **13** is a cross-sectional view illustrating a lens barrel on which the vibration wave motor is mounted.
[0025] FIG. **14** is a cross-sectional view illustrating a lens barrel on which the annular type vibration wave motor according to embodiment 2 is mounted.
[0026] FIG. **15** is an explanatory view illustrating the vibrator according to embodiment 3.
[0027] FIG. **16** is an explanatory view illustrating a driving principal of the vibrator according to embodiment 3.
[0028] FIG. **17** is an explanatory view illustrating an example of the dust proof device according to embodiment 4.
[0029] FIG. **18** is a graph illustrating an example of temperature characteristics of an electrostatic capacitance of PZT (made by Fuji Ceramics Corporation) which is a material of the piezoelectric body prepared for the vibration wave motor.
[0030] FIG. **19**A is a graph illustrating an example of temperature characteristics of an electrostatic capacitance of the vibrator of the vibration wave motor in a case where the PZT in FIG. **18** is a piezoelectric body material (part **1**).
[0031] FIG. **19**B is a graph illustrating an example of temperature characteristics of an electrostatic capacitance of the vibrator of the vibration wave motor in a case where the PZT in FIG. **18** is a piezoelectric body material (part **2**).

[0032] FIG. **20** is a graph obtained by measuring a current input at each temperature for the vibration wave motor of a PZT-mounted product.

DETAILED DESCRIPTION OF THE EMBODIMENTS

[0033] A vibration wave motor produces a traveling wave on a driving surface of an elastic body by using expansion and contraction of a piezoelectric body, this traveling wave causes an elliptical motion on the driving surface, and a mover placed in pressure contact with a crest of the elliptical motion is driven. Features of the vibration wave motor include that the vibration wave motor has a high torque even in a case of low rotation, and in a case where the vibration wave motor is mounted on a driving device, a gear of the driving device can be omitted. Consequently, by canceling gear noise, it is possible to achieve noise reduction, and improve positioning accuracy.

[0034] A vibrator of this vibration wave motor generally includes an electromechanical transducer (abbreviated as a piezoelectric body below) and an elastic body. The piezoelectric body is generally formed by a material such as lead zirconate titanate which is commonly called PZT.

[0035] FIG. **18** is a graph illustrating an example of temperature characteristics of an electrostatic capacitance of PZT (made by Fuji Ceramics Corporation) which is a material of the piezoelectric body prepared for the vibration wave motor. It is found that the electrostatic capacitance has an inclination of approximately 4.4 [pF/° C.] (˜ **2750** [ppm/° C.]) with respect to a temperature.

[0036] FIG. **19**A is a graph illustrating an example of temperature characteristics of an electrostatic capacitance of the vibrator of the vibration wave motor in a case where the PZT in FIG. **18** is a piezoelectric body material (part **1**). FIG. **19**B is a graph illustrating an example of temperature characteristics of an electrostatic capacitance of the vibrator of the vibration wave motor in a case where the PZT in FIG. **18** is a piezoelectric body material (part **2**). It is found that the electrostatic capacitances have an inclination of approximately 6.2 [pF/° C.] (˜ **4430** [ppm/° C.]) with respect to a temperature. This inclination indicates that, for example, when the temperature becomes lower, the electrostatic capacitance of the piezoelectric body decreases more, and, when the temperature becomes higher, the electrostatic capacitance of the piezoelectric body increases more.

[0037] FIG. **20** is a graph obtained by measuring a current input at each temperature for the vibration wave motor of a PZT-mounted product. At each time of measurement, a drive voltage was set to 70 [Vrms], and a current input to the vibration wave motor at a time when the vibration wave motor was driven at a predetermined rotation speed was measured. A phenomenon is that, while an input current decreases more when the temperature becomes lower, the input current increases more when the temperature becomes higher compared to a current at a normal temperature. This phenomenon matches with temperature characteristics of an electrostatic capacitance value of the vibrator illustrated in FIGS. **19**A and **19**B.

[0038] Although the electrostatic capacitance of the vibrator decreases more when the temperature becomes lower, an impedance increases, and therefore the input current decreases, the electrostatic capacitance of the vibrator increases more when the temperature becomes higher, the impedance decreases, and therefore the input current increases accordingly. Accordingly, when the temperature becomes higher, the electrostatic capacitance of the vibrator increases more, and therefore the vibration wave motor cannot be efficiently driven.

[0039] While the vibration wave motor generates a driving force according to a drive signal supplied from a driving device, and can obtain desired driving performance under a certain drive signal condition such as an appropriate voltage value, and the voltage of this drive signal changes depending on the electrostatic capacitance of the piezoelectric body.

[0040] There is also a driving device which includes a matching circuit which matches an impedance of a driving circuit which drives a piezoelectric motor and an impedance of the piezoelectric motor. The PZT has great temperature characteristics as illustrated in FIG. **18**, and therefore even when this driving device adjusts a voltage to an appropriate voltage at a normal temperature, a driving voltage at a low temperature and a driving voltage at a high temperature significantly differ. Therefore, it is not possible to sufficiently exhibit driving performance (driving

efficiency or a driving force) of the vibration wave motor.
[0041] According to the present embodiment, a material free of lead is applied to the piezoelectric body to improve driving performance of the vibration wave motor in order to deal with environmental issues. The vibrator and the vibration wave motor according to the present embodiment will be described below citing embodiment 1 to embodiment 4.
Embodiment 1
<Vibration Wave Motor>
[0042] FIG. **1** is a cross-sectional view illustrating a vibration wave motor according to embodiment 1. FIG. **2** is a perspective view illustrating that part of a vibrator **10** and a mover **20** are cut out. Embodiment 1 employs a configuration where the vibrator **10** side is fixed, and the mover **20** which is one example of a relative motion member is driven. The mover **20** is made of a light metal such as aluminum. Surface treatment for improving abrasion resistance is performed on a sliding surface **20***a* of the mover **20**.
[0043] The vibrator **10** includes an electromechanical transducer (abbreviated as a piezoelectric body below) **11** which is, for example, a piezoelectric element or an electrostrictive element which converts electric energy into mechanical energy, and an elastic body **12** to which the piezoelectric body **11** is bonded, and the vibrator **10** produces a traveling vibration wave.
[0044] The elastic body **12** is made of a metal material whose resonance sharpness is great, and has an annular shape. The piezoelectric body **11** is bonded to one surface (bonding surface **12***f*) of the elastic body **12**, and grooves **12***b* are engraved on a side opposite to this bonding surface **12***f*. Furthermore, distal ends of protrusion portions (portions without the grooves **12***b*) **12***c* become driving surfaces **12***a*, and are placed in pressure contact with the sliding surface **20***a* of the mover **20**. Lubricant surface treatment is performed on the driving surfaces **12***a*.
[0045] A part at which the grooves **12***b* of the elastic body **12** are not engraved is a base part **12***d*, and a flange **12***e* is extended from the base part **12***d* to an inner diameter side. An innermost diameter part of the flange **12***e* is fixed to a fixing member **13**. A sliding member such as a coating film or lubricant plating is applied to the protrusion portions **12***c* of the elastic body **12** to cover the entire protrusion portions **12***c*.
[0046] Although described in detail later, the piezoelectric body **11** is made of a material which is a material free of lead and whose main ingredients are potassium-sodium niobate. A flexible printed circuit board (FPC) **14** is bonded to a surface (opposite bonding surface) of the piezoelectric body **11** on an opposite side to the bonding surface **12***f* of the elastic body **12** to transmit a drive signal, and extends to a circuit board. Electrodes are arranged on the opposite bonding surface, and form a two-group structure which is grouped into two phases (an A phase and a B phase) along a circumferential direction. The electrodes are arranged in each phase such that the electrodes are alternately polarized per ½ wavelength, and an interval corresponding to a ¼ wavelength is secured between the A phase and the B phase.
[0047] An output shaft **21** is coupled to the mover **20** by means of a rubber member **22** and a stopper member **23** inserted to so as to fit to a D cut of the output shaft **21**. Furthermore, the output shaft **21** and the stopper member **23** are fixed by an E clip **24**, and rotate together with the mover **20**.
[0048] The rubber member **22** between the stopper member **23** and the mover **20** has a function of coupling the mover **20** and the stopper member **23** by adhesiveness of a rubber, and is suitably, for example, a butyl rubber which has a vibration absorption function of preventing vibration from the mover **20** from transmitting to the output shaft **21**. A pressurizing member **25** is provided between an output gear **41** of the output shaft **21** and a bearing **27**. According to this structure, the mover **20** is placed in pressure contact with the driving surface **12***a* of the elastic body **12**.
<Driving Device of Vibration Wave Motor>
[0049] FIG. **3** is a block diagram illustrating a driving device **300** of a vibration wave motor **1** according to embodiment 1. The driving device **300** includes a control unit **301**, an oscillation unit

302, a phase unit **303**, an amplification unit **304**, the vibration wave motor **1**, and a detection unit **305**. The control unit **301** is electrically connected with a CPU **310** in a lens barrel **110** (see FIG. **13**) or of a camera main body.

[0050] The control unit **301** controls driving of the vibration wave motor **1** based on a drive command from the CPU **310** in the lens barrel **110** or of the camera main body. The control unit **301** receives a detection signal from the detection unit **305**, obtains position information and speed information based on a value of this detection signal, and controls a frequency of the oscillation unit **302** such that positioning is performed at a target position.

[0051] The oscillation unit **302** generates a drive signal of a desired frequency according to a command of the control unit **301**. The phase unit **303** divides the drive signal generated by the oscillation unit **302** into two drive signals of different phases. The amplification unit **304** respectively boosts the two drive signals divided by the phase unit **303** to desired voltages. The drive signals from the amplification unit **304** are transmitted to the vibration wave motor **1**, the vibrator **10** produces a traveling wave when applied these drive signals, and the mover **20** is driven.

[0052] The detection unit **305** includes, for example, an optical encoder or a magnetic encoder, and detects a position and a speed of a driving object driven by driving of the mover **20**, and transmits a detection value as an electric signal to the control unit **301**.

[0053] Next, an operation of the vibration wave motor **1** will be described. When the control unit **301** issues the drive command, the oscillation unit **302** generates a drive signal. This drive signal is divided into two drive signals whose phases are different by 90 degrees by the phase unit **303**, and is amplified to desired voltages by the amplification unit **304**. The amplified drive signals are applied to the piezoelectric body **11** of the vibration wave motor **1**, and the piezoelectric body **11** is excited (vibrated). When the piezoelectric body **11** is excited, the elastic body **12** causes quaternary bending vibration. The piezoelectric body **11** is grouped into the A phase and the B phase, and the drive signals are respectively applied to the A phase and the B phase.

[0054] Positional phases of quaternary bending vibration caused by the A phase and quaternary bending vibration caused by the B phase are shifted by a ¼ wavelength. Furthermore, phases of an A phase drive signal and a B phase drive signal are shifted by 90 degrees, and therefore the two bending vibrations are synthesized, and become traveling waves of four waves.

[0055] An elliptical motion occurs at a crest of a traveling wave. Thus, the mover **20** placed in pressure contact with the driving surface **12***a* is driven causing friction by this elliptical motion. The optical encoder which is the detection unit **305** is arranged on a driving body driven by driving of the mover **20**, and the optical encoder generates an electric pulse to transmit to the control unit **301**. The control unit **301** can obtain a current position and a current speed based on a signal of this electric pulse.

<Piezoelectric Body **11**>

[0056] FIG. **4** is an explanatory view illustrating the piezoelectric body **11** according to embodiment 1. FIG. **4** (*a*) is a view illustrating a top surface **11**A of the piezoelectric body **11**, and FIG. **4** (*b*) is a view illustrating a back surface **11**B of the piezoelectric body **11**. FIG. **5** is an explanatory view illustrating the vibrator **10** according to embodiment 1. FIG. **5** (*a*) is a view illustrating a side surface of the vibrator **10**, and FIG. **5** (*b*) is a view illustrating the vibrator **10** seen from a side of the top surface **11**A of the piezoelectric body **11**.

[0057] In the top surface **11**A, electrodes **16** are grouped into two phases (the A phase and the B phase) along the circumferential direction. In each phase, the electrodes **16** are alternately polarized per ½ wavelength, and the electrodes **16** are printed on a base **18** of the piezoelectric body **11** by a silver paste such that an interval corresponding to a ¼ wavelength is secured between the A phase and the B phase. The electrodes **16** may be metal plating such as NiP or gold. The base **18** of the piezoelectric body **11** is formed by a lead-free material whose main ingredients are sodium-potassium niobate.

[0058] The back surface **11**B has a shape on which an electrode **19** which is not like an electrode pattern of the electrodes **16** is printed by a silver paste, and in which the base **18** of the piezoelectric body **11** appears at an outer circumferential side and an inner circumferential side. The electrode **19** may be metal plating such as NiP or gold. The back surface **11**B is bonded to the elastic body **12** by a cold curing adhesive.

[0059] Furthermore, the FPC **14** is bonded to the top surface **11**A to transmit drive signals from the driving device **300**, and is connected with the driving device **300**. A GND wire of the FPC **14** is bonded to the electrodes **16** of the ¼ wavelength, is bonded to the electrodes **16** of the ¼ wavelength and a metal part of the elastic body **12** crossing using an unillustrated conductive coating, and thereby is grounded to the metal part of the elastic body **12**.

[0060] Hereinafter, a material of the piezoelectric body **11** will be described. The material of the piezoelectric body **11** is a piezoelectric ceramic made of sodium-potassium niobate metal oxides, and a following material and manufacturing method are used, for example. The material of the piezoelectric body **11** is expressed by following chemical formula (1).

.sub.(1-C-E)(*Li*.sub.A(*Na*.sub.B*K*.sub.(1-B)).sub.(1-A)*NbO*.sub.3+.sub.C*Ba*(*Zr*.sub.D*Ti*.sub.(1-D))*O*.sub.3+EBiFeO.sub.3

where $0<A<0.2$, $0.4\leq B\leq 0.6$, $0<C\leq 0.1$, $0<D<1.00$, and $0<E<0.02$ hold (1)

[0061] The material of this piezoelectric body **11** has a very little temperature characteristics of a relative permittivity. More specifically, a change percentage of the relative permittivity is 500 [ppm/° C.] or less in absolute value in a range of −40° C. to 170° C., that is, is in a range of −500 to +500 [ppm/° C.]. Consequently, it is possible to make the temperature characteristics of an electrostatic capacitance of the piezoelectric body **11** a little very much.

[0062] Use of sodium carbonate and potassium carbonate in the material makes pH of a slurry at a time of mixing and at a time of pulverization strong alkaline. Hence, according to the present embodiment, sodium niobate and potassium niobate which are prepared by a hydrothermal synthesis method and whose grain sizes are nano sizes are used for the material. Consequently, it is possible to make pH weak alkaline.

[0063] Furthermore, sodium and niobium, and potassium and niobium of sodium niobate and potassium niobate whose composition ratios (x) are in a range of $1.00\leq x\leq 1.01$ may be used. According to a manufacturing method described below, the range of (x) was changed to check a difference between a case where (x) was 1.00 and a case where (x) was 1.01.

[0064] The manufacturing method will be more specifically described below. A and B were respectively changed in a following range based on chemical formula .sub.(1-C-E) (Li.sub.A (Na.sub.BK.sub.(1-B)).sub.(1-A) NbO.sub.3 as a composition of a niobium non-lead piezoelectric ceramic material to carry out the manufacturing method.

$0.055\leq A\leq 0.1$

$0.4\leq B\leq 0.6$

[0065] Barium zirconate titanate and bismuth ferrite were added thereto to prepare the composition.

.sub.(1-C-E)(*Li*.sub.A(*Na*.sub.B*K*.sub.(1-B)).sub.(1-A)*NbO*.sub.3+C*Ba*(*Zr*.sub.D*Ti*.sub.(1-D)*O*.sub.3+EBiFeO.sub.3

[0066] ($0.055\leq A\leq 0.1$, $0.4\leq B\leq 0.6$, $0.05\leq C\leq 0.1$, $0.17\leq D\leq 0.83$, and $0.005\leq E\leq 0.01$)

[0067] According to a blending method according to the present embodiment, 0.055 mol to 0.1 mol of lithium carbonate, 0.05 mol to 0.1 mol of barium carbonate, 0.05 mol to 0.1 mol of zirconium oxide, 0.05 mol to 0.1 mol of titanium oxide, 0.005 mol to 0.01 mol of bismuth oxide, and 0.005 mol to 0.01 mol of iron oxide were blended at this rate.

[0068] Furthermore, a blending amount of a composition of a material α in FIG. **6** which was

blended such that an entire blending amount was in a scale of 100 g, and a preparation method thereof will be described as a typical example.
[0069] FIG. **6** is a table illustrating constants (A to E), an electromechanical coupling factor, a relative permittivity, a piezoelectric constant, and temperature characteristics of the relative permittivity (change percentage) of chemical formula (1) of each material. The temperature characteristics of the relative permittivity were measured in two temperature ranges (−40 to 170° C. and 0 to 60° C.). When the electromechanical coupling factor is larger, electric energy is more efficiently converted into mechanical energy. In addition to these ingredients, 0.1 wt % of Cu was added to a material γ. Thus, a mechanical quality factor (described later with reference to FIG. **11**) improves.
[0070] According to the blending amount of the composition of the material α in FIG. **6** and the preparation method thereof, 0.057 mol of lithium carbonate, 0.05 mol of barium carbonate, 0.0415 mol of zirconium oxide, 0.0085 mol of titanium oxide, 0.005 mol of bismuth oxide, and 0.005 mol of iron oxide were blended at this rate, and were mixed and milled in 300 ml of water for 24 hours by a ball mill to prepare a primary mixing and milling solution. Furthermore, compared to the blending amount of the composition of the material α in FIG. **6**, blending amounts of compositions of A to E in other Nos. are determined based on varying percentage proportions with respect to the material α.
[0071] 0.444 mol of sodium niobate and 0.444 mol of potassium niobate prepared by the hydrothermal synthesis method by being subjected to solvothermal reaction with this primary mixing and milling solution at 150° C. to 300° C. for 1 to 12 hours was blended to prepare a mixture. This mixture was mixed and milled in 300 ml of water at a room temperature for 24 hours by the ball mill again to prepare a secondary mixing and milling solution. Subsequently, this secondary mixing and milling solution was dried at 85° C. for 48 hours in a state where the secondary mixing and milling solution was weak alkaline at pH 8.9 to pH 9.8 equal to or less than pH 10 to prepare a dried material.
[0072] Next, this dried material was subjected to temporary calcination twice in a range of 700° C. to 800° C. The first temporary calcination was performed at 800° C. for two hours by using an electric furnace, resulting temporary calcination powder was then milled in 300 ml of water for 24 hours by the ball mill, was dried at 85° C. for 48 hours by using a thermostat bath, and, after primary temporary calcination milled dried powder was prepared, temporary calcination was performed again.
[0073] A temperature range of second temporary calcination was 800° C. which was the same temperature condition as that of the first temporary calcination, and the time was two hours. In this regard, the first temporary calcination and the second temporary calcination may be performed under a condition that calcination temperatures are different. Although a calcination atmosphere condition was that calcination was performed in atmospheric air in the present embodiment, calcination can be also performed in an atmosphere other than air. For example, manufacturing can be performed in an oxygen atmosphere.
[0074] A temporary calcination powder milling method was a method such as a ball mill or a bead mill, and second calcination powder was milled in 300 ml of water for 24 hours by the ball mill such that a grain size of second temporary calcination milled dried powder became 1 μm or less, and was dried at 85° C. for 48 hours by using the thermostat bath to prepare second temporary calcination milled dried powder.
[0075] Subsequently, the second temporary calcination milled dried powder and 10 wt % of a binder were mixed, were let pass a #40 mesh screen, and were dried at 110° C. for one hour by using the thermostat bath to prepare granulated powder of granules.
[0076] After granulation, the granulated powder was loaded to a mold of φ15 mm, was pressurized by using a hydraulic press machine (200 ton press), and was molded such that a molding density (p) was approximately 2.3 g/cm.sup.3 to 2.6 g/cm.sup.3 and the thickness of a molded material was

1.5 mm. A time for pressurization was 1 to 10 seconds. Note that the molding density (p) was approximately 2.3 to 2.6 g/cm.sup.3, and molding was performed by changing the molding density in a range of 2.6 g/cm.sup.3 which was an upper limit to 2.3 g/cm.sup.3 which was a lower limit. A result of molding showed that 2.5 g/cm.sup.3 was optimal.

[0077] Although degreasing is performed in a temperature range of 700° C. to 800° C. by using the electric furnace after molding, it is preferable to maintain the temperature range at 700° C. for four hours, and then perform calcination in a calcination temperature range of 1100° C. to 1250° C. in the embodiment. Calcination was performed at 1200° C. in the embodiment. Calcination was performed in an atmosphere such as air at a time of calcination.

[0078] After calcination, a calcined material was machined to a thickness of T=0.5 mm by using a grinding machine (6 BN, HAMAI and number #800 abrasive), and a silver paste (SR-2099 made by Namics Corporation) was applied to a surface of a machined element by a screen printing method to provide the element with silver electrodes at 800° C. by using the electric furnace. This element with the silver electrodes was applied a voltage of 4.0 kV/mm in an insulating oil (silicon oil) of 50° C. for 10 minutes, and polarized to manufacture a niobium non-lead piezoelectric ceramic.

[0079] Furthermore, according to a method for measuring a niobium non-lead piezoelectric ceramic material, the niobium non-lead piezoelectric ceramic material was left for 24 hours after polarization processing, and measured by a resonance-antiresonance method by using an impedance analyzer (device 4294A manufactured by Agilent Technologies, Inc.). Furthermore, an equivalent piezoelectric constant was measured by using a d33 meter (ZJ-43 manufactured by Institute of Acoustics, Chinese Academy of Sciences).

[0080] The niobium non-lead piezoelectric ceramic according to the present embodiment was obtained by this manufacturing method. The electromechanical coupling factor, the relative permittivity, the piezoelectric constant, the temperature characteristics of the relative permittivity and temperature characteristics of a Curie point of the resulting niobium non-lead piezoelectric ceramic were measured by a following method.

<Measurement Device and Measurement Method>

[0081] A method for measuring the temperature characteristics of the relative permittivity of the niobium non-lead piezoelectric ceramic material prepared by the manufacturing method according to the present embodiment will be described.

[0082] The piezoelectric body **11** having a shape whose diameter was φ10×T0.5 mm and obtained herein was left for 24 hours, a small ultra-low incubator (MC-811, ESPEC CORP.) was used, and an electrostatic capacitance at a time when a frequency was 1 kHz and a voltage was 0.5 V was measured by using the impedance analyzer (device 4294A manufactured by Agilent Technologies, Inc.) every 10° C. from −40° C. to 170° C. and from 170° C. to −40° C. to calculate the relative permittivity. A result thereof is shown in FIG. **7**.

[0083] FIG. **7** is a view of temperature characteristics of a relative permittivity. FIG. **7** illustrates a change in the relative permittivity at a time when measurement was performed by raising a temperature in a temperature range from −40° C. to 170° C. and dropping a temperature from 170° C. to −40° C. to the contrary. A difference between values of the relative permittivity according to the present embodiment at the time of the temperature rise when measurement was performed from the low temperature side of −40° C. and at the time of the temperature drop from when measurement was performed from the high temperature side of 170° C. was maximum 38 and small, and a hysteresis value of the relative permittivity before and after phase transition was in a range of 32 to 38.

[0084] It is generally known that, in a case of a material such as crystal, a relative permittivity changes little in a temperature range of −40° C. to 170° C. Even according to the present embodiment, it has been confirmed that a material having sufficient practicality can be provided in this range as shown in FIG. **7**.

<Temperature Characteristics of Electrostatic Capacitance of Piezoelectric Body **11**>

[0085] FIG. **8**A**1** is a graph illustrating temperature characteristics of electrostatic capacitances of materials α and β of the piezoelectric body **11** according to embodiment 1 (part **1**). FIG. **8**A**2** is a graph illustrating temperature characteristics of electrostatic capacitances of materials α and β of the piezoelectric body **11** according to embodiment 1 (part **2**). FIG. **8**B is a graph illustrating temperature characteristics of an electrostatic capacitance of the material γ of the piezoelectric body **11** according to embodiment 1. In FIGS. **8**A and **8**B, for example, a temperature higher than −20° C. and equal to or less than 0° C. is a low temperature range, a temperature higher than 0° C. and equal to or less than 25° C. is a normal temperature range, and a temperature higher than 25° C. and equal to or less than 60° C. is a high temperature range. Regarding changes in the electrostatic capacitances of the materials α, β, and γ from the time of the low temperature to the time of the high temperature, in a case where 60° C. serves as a reference point, fluctuation of the material α is approximately 2% at 0° C., and approximately 10% at −20° C. Fluctuation of the material β is approximately 4% at 0° C., and approximately 11% at −20° C. Fluctuation of the material γ is approximately 1% at 0° C., and approximately 5% at −20° C.

<Temperature Characteristics of Electrostatic Capacitance of Vibrator **10**>

[0086] FIG. **9**A**1** is a graph illustrating temperature characteristics of electrostatic capacitances of the vibrator **10** in a case where the materials α and β are used (part **1**). FIG. **9**A**2** is a graph illustrating temperature characteristics of electrostatic capacitances of the vibrator **10** in a case where the materials α and β are used (part **2**). FIG. **9**B is a graph illustrating temperature characteristics of an electrostatic capacitance of the vibrator **10** according to embodiment 1 in a case where the material γ is used. Regarding changes in the electrostatic capacitances of the vibrator **10** from the time of the low temperature to the time of the high temperature, in a case where 60° C. serves as a reference point, fluctuation of the material α is approximately 8% at 0° C., and approximately 18% at −20° C. Fluctuation of the material β is approximately 10% at 0° C., and approximately 20% at −20° C. Fluctuation of the material γ is approximately 6% at 0° C., and approximately 16% at −20° C. These fluctuations are much smaller than 25% at 0° C. and 31 to 33% at −20° C. which are change percentages in a case where PZT is mounted.

<Consumption Current Measurement>

[0087] FIG. **10**A is a graph illustrating a measured consumption current at each temperature for the vibration wave motor **1** according to embodiment 1 and a vibration wave motor which is a PZT-mounted product (part **1**). FIG. **10**B is a graph illustrating a measured consumption current at each temperature for the vibration wave motor **1** according to embodiment 1 and a vibration wave motor which is a PZT-mounted product (part **2**). A drive voltage was set to 70 [Vrms] per measurement to measure a current input to the vibration wave motor at a time when the vibration wave motor was driven at a predetermined rotation speed. It is found that the vibration wave motor **1** on which the materials α, β, and γ are mounted has little temperature characteristics of the input current. Upon comparison with the temperature characteristics of the input current of the PZT-mounted product illustrated in FIGS. **19**A and **19**B, it is found that the vibration wave motor **1** can be more efficiently driven than the PZT-mounted product particularly at a high temperature. This phenomenon is caused by the temperature characteristics of the electrostatic capacitance of the vibrator **10** as described above. This phenomenon will be described with reference to FIG. **11**.

[0088] FIG. **11** is an explanatory view illustrating an equivalent circuit of the vibrator **10** of the vibration wave motor **1**. An equivalent circuit **1100** of the vibrator **10** includes an electrostatic capacitance Cd of the piezoelectric body **11**, an equivalent inductance L, an equivalent capacitance C, and a resonant resistance R. A current Ia of the vibrator **10** is a sum of a current Ib (following equation (2)) to a component of the electrostatic capacitance Cd of the piezoelectric body **11** and a current Ic (following equation (3)) to an LCR series side.

[00001] $\mathrm{Ib} = E/(1/j\quad \mathrm{Cd})$ (2) [0089] where E represents a drive voltage, w represents an

angular frequency, and f represents a frequency of a drive signal.

[00002] $Ic = \frac{E}{R+j(\ L+1/\ C)}$ (3) [0090] where Ia≈Ib holds in state of 1/jωCd<<R+j (ωL+1/ωC).

[0091] Generally, a vibration wave motor is driven at a driving frequency which is slightly apart toward a high frequency side from a resonance frequency at which an impedance of an equivalent circuit **900** is minimum and an antiresonance frequency at which the impedance of the equivalent circuit **900** is maximal. Under a condition of this driving frequency, a value of 1/ωCd which is a denominator of the current Ib is much smaller than a value of R+ (ωL−1/ωC) which is a denominator of the current Ic, and therefore the current Ia input to the vibrator **10** takes the substantially same value as that of the current Ib. That is, a consumption current of the vibrator **10** substantially depends on whether the value of the electrostatic capacitance Cd of the piezoelectric body **11** is large or small.

[0092] Hence, when the electrostatic capacitance of the vibrator **10** changes due to a temperature, an impedance also changes, and a current to be input changes. The electrostatic capacitance of the products on which the materials α, β, and γ are mounted increases little even when a temperature becomes high, and therefore a current to be input also increases little.

[0093] Furthermore, a general vibration wave motor is designed to match an impedance of a driving device and an impedance of a vibration wave motor. Hence, when the value of the electrostatic capacitance Cd of the piezoelectric body **11** changes, a voltage of a drive signal (drive voltage E) changes. Therefore, when the electrostatic capacitance Cd of the piezoelectric body **11** is fluctuated by an environmental temperature, the voltage of the drive signal also fluctuates.

[0094] Even when the vibration wave motor on which PZT is mounted adjusts the voltage to an appropriate voltage at a normal temperature, the drive voltage at a low temperature and a drive voltage at a high temperature significantly differ. More specifically, a phenomenon that, compared to the voltage at the time of the normal temperature, the drive voltage is high at the time of the low temperature, and the drive voltage is low at the time of the high temperature occurs. A higher drive voltage than an originally necessary drive voltage is set at the time of the low temperature, and the high voltage undermines driving efficiency of the drive circuit itself. A change in the electrostatic capacitance of the vibration wave motor **1** according to embodiment 1 at the time of the low temperature and at the time of the high temperature is a little compared to the PZT-mounted product, so that it is possible to substantially make fluctuation of the drive voltage a very little, and driving efficiency of the driving device 300 itself is improved.

[0095] Q in following equation (4) represents a mechanical quality factor. Values of the equivalent inductance L and the equivalent capacitance C influence resonance characteristics of the vibrator **10**. The mechanical quality factor Q is a scale which indicates resonance characteristics, and a higher value of the mechanical quality factor Q indicates better resonance characteristics. The mechanical quality factor Q becomes larger as an Lm value becomes larger. Compared to the material B, the material γ illustrated in FIG. **6** provides the larger mechanical quality factor Q, and improved resonance characteristics.

[00003] $Q = \frac{1}{2\ \mathrm{fCR}} = \frac{2\ \mathrm{fL}}{R}$ (4)

[0096] Furthermore, it is also found that the vibration wave motor **1** according to embodiment 1 has a little temperature characteristics of a drivable voltage.

[0097] FIG. **12** is a table showing a lowest voltage (referred to a drivable voltage below) of a drive signal which can drive the vibration wave motor **1** according to embodiment 1. The vibration wave motor **1** cannot be driven at the drive voltage E which is lower than a value of the drivable voltage. In a case of each of the materials α, β, and γ, the drivable voltages change little in a range to 0 to 50° C. in temperature at which the electrostatic capacitances change little. Although the drivable voltages become higher a little at −20° C., fluctuation amounts are a very little compared to a case where the PZT is mounted.

[0098] An experiment conducted by the inventors of the present invention shows that the drivable voltage and the electrostatic capacitance of the vibrator **10** correlate. This reason will be described. An electromechanical coupling factor Kvn of the vibrator **10** is expressed by following equation (5) as a quantity converted from electric energy Ui stored in the vibrator **10** into mechanical energy Ut which is strain energy of vibration.

[00004] $Kvn = (Ut / Ui)^{0.5}$ (5)

[0099] Almost all of the electric energy Ui stored in the vibrator **10** is stored in the piezoelectric body **11**. On the other hand, energy Pf stored in the piezoelectric body **11** is as expressed by following equation (6).

[00005] $Pf = E \times \quad \times Cdv$ (6)

[0100] E represents a drive voltage, w represents an angular frequency, and Cdv represents an electrostatic capacitance of the vibrator **10**. A state where the vibration wave motor **1** is drivable is a state where strain energy reaches a certain threshold or more. When the electromechanical coupling factor Kvn and w take certain values, the strain energy of the certain threshold depends on a value of the electrostatic capacitance Cdv of the vibrator **10** and a voltage value to be applied. However, it is thought that the electrostatic capacitance Cdv of the vibrator **10** of the PZT-mounted product is fluctuated by a temperature, and therefore a drivable voltage changes accompanying the fluctuation.

[0101] When driving is performed using a drive signal of a certain voltage, the drivable voltage at −20° C. at which the drivable voltage becomes high is set as a reference point to set the drive voltage E to the PZT-mounted product. However, a difference between the drive voltages E and the drivable voltages at a normal temperature and a high temperature becomes significant, and therefore an extra current larger than an originally necessary current is input. On the other hand, the temperature characteristics of the drivable voltage of the vibration wave motor **1** according to embodiment 1 are a little, a difference between the drive voltage and the drivable voltage at each temperature does not change so much, and therefore a substantially necessary current is input at each temperature.

<Lens Barrel>

[0102] FIG. **13** is a cross-sectional view illustrating a lens barrel **110** on which the vibration wave motor **1** is mounted. The lens barrel **110** includes an outer fixed cylinder **31**, an inner fixed cylinder **32**, and the vibration wave motor **1**. The outer fixed cylinder **31** has, for example, a cylindrical shape, and covers an outer circumferential part of the lens barrel **110**. The outer fixed cylinder **31** includes a protrusion piece **31***a* which protrudes from an inner circumferential surface of the outer fixed cylinder **31** to an optical axis OA. The protrusion piece **31***a* supports the inner fixed cylinder **32**. The inner fixed cylinder **32** has, for example, a cylindrical shape, and is provided on an inner circumferential side compared to the outer fixed cylinder **31**. The vibration wave motor **1** is provided between the outer fixed cylinder **31** and the inner fixed cylinder **32**.

[0103] In the inner fixed cylinder **32**, a first lens group L**1**, a second lens group L**2**, a third lens group L**3**, and a fourth lens group L**4** are arranged on the identical optical axis OA in order from a subject side. The third lens group L**3** is an AF lens held by an annular Auto Focus (AF) ring **119**. The first lens group L**1**, the second lens group L**2** and the fourth lens group L**4** are fixed to the inner fixed cylinder **32**. The third lens group L**3** is configured to be able to move in a direction of the optical axis OA (referred to as an optical axis direction below) with respect to the inner fixed cylinder **32** when the AF ring **119** moves.

[0104] The vibration wave motor **1** is attached to a gear unit module **113**. The gear unit module **113** is attached to the inner fixed cylinder **32** of the lens barrel **110**. The output gear **41** of the vibration wave motor **1** transmits a rotational motion to a cum ring **116** via a deceleration gear **115** of the gear unit module **113**, and the cum ring **116** is rotated and driven.

[0105] A key groove **117** is engraved in the cum ring **116** diagonally in a circumferential direction. The AF ring **119** includes a fixing pin **118**. The fixing pin **118** is inserted in the key groove **117**.

When the cum ring **116** is rotated and driven in a state where the fixing pin **118** is inserted in the key groove **117**, the AF ring **119** is driven in a direction straight to the optical axis OA direction, and can stop at a desired position. The driving device **300** illustrated in FIG. **2** is provided between the outer fixed cylinder **31** and the inner fixed cylinder **32** of the lens barrel **110** to drive and control the above-described vibration wave motor **1**, and detect a rotational speed.

[0106] Consequently, the vibration wave motor **1** according to embodiment 1 can make temperature characteristics of a consumption current a little compared to the PZT-mounted product. Furthermore, the change in the electrostatic capacitance Cdv of the vibrator **10** at the time of the low temperature and at the time of the high temperature is a little compared to the PZT-mounted product, so that it is possible to substantially make fluctuation of the drive voltage E a very little, and the driving efficiency of the driving device 300 itself is improved. Furthermore, the electrostatic capacitance Cdv of the vibrator **10** is fluctuated little by an environmental temperature compared to the PZT-mounted product, so that it is possible to make a temperature change in a drivable voltage of the vibration wave motor **1** a little.

Embodiment 2

[0107] Embodiment 2 is an example where the vibration wave motor **1** according to embodiment 1 is an annular type vibration wave motor. The same components as those of embodiment 1 will be assigned the same reference numerals, and description thereof will be omitted.

[0108] FIG. **14** is a cross-sectional view illustrating a lens barrel on which the annular type vibration wave motor according to embodiment 2 is mounted. A lens barrel **200** includes the outer fixed cylinder **31** and the inner fixed cylinder **32**, and adopts a mechanism that a motor unit including an annular type vibration wave motor **210** is fixed to the outer fixed cylinder **31** and the inner fixed cylinder **32**. The driving device 300 is provided between the outer fixed cylinder **31** and the inner fixed cylinder **32** of the lens barrel **200** to drive and control the vibration wave motor **210**, and detect a rotational speed. The driving device 300 matches an impedance of the driving device 300 and an impedance of the vibration wave motor.

[0109] Next, a configuration of the vibration wave motor **210** will be described. The vibrator **211** includes the piezoelectric body **11** which is made of the same sodium-potassium niobate metal oxides as those of embodiment 1, and an elastic body **214** to which the piezoelectric body **11** has been bonded. Although the vibrator **211** produces traveling waves, traveling waves of nine waves will be described as an example in embodiment 2.

[0110] The elastic body **214** is made of a metal material whose resonance sharpness is great. The shape of the elastic body **214** is an annular shape. Grooves are engraved on an opposite surface of the elastic body **214** to which the piezoelectric body **11** is bonded. A reason for engraving the grooves is to place the piezoelectric body **11** side close to neutral surfaces of the traveling waves as much as possible, and thereby amplify the amplitudes of the traveling waves of a driving surface **216***a*. A surface of a part which is not provided with the grooves is the driving surface **216***a*, and is placed in pressure contact with a mover **220**. A lubricant coating film is applied to the surface of the driving surface **216***a* of the elastic body **214** to secure driving performance and improve durability.

[0111] The piezoelectric body **11** is grouped into two phases (the A phase and the B phase) along the circumferential direction similar to embodiment 1, elements are arranged in each phase such that the elements are alternately polarized per ½ wavelength, and an interval corresponding to a ¼ wavelength is secured between the A phase and the B phase. The piezoelectric body **11** is formed by the same material as that of embodiment 1, and is formed by a material whose temperature characteristics of a relative permittivity are a very little, that is, a material whose temperature characteristics of the electrostatic capacitance Cd are a little.

[0112] Under the piezoelectric body **11**, a non-woven fabric **252** and a pressurizing member **250** are arranged. The non-woven fabric **252** is, for example, a felt, and is arranged under the piezoelectric body **11** to prevent vibration of the vibrator **211** from transmitting to the pressurizing member **250**.

[0113] The pressurizing member **250** is arranged under a pressure plate (not illustrated) to generate a pressurizing force. In embodiment 2, the pressurizing member **250** is a disc spring. The pressurizing member **250** may be a coil spring or a wave spring instead of the disc spring. A retention ring **251** is fixed to a fixing member **223**, and thereby the pressurizing member **250** is held.

[0114] The mover **220** is made of a light metal such as aluminum, and a sliding material is provided on a surface of a sliding surface to improve abrasion resistance. A vibration absorption member **243** such as a rubber is arranged on the mover **220** to absorb longitudinal vibration of the mover **220**, and an output transmission member **242** is arranged thereon.

[0115] A pressurizing direction and a radial direction of the output transmission member **242** are regulated by a bearing **253** provided to the fixing member **223**, and thereby a pressurizing direction and a radial direction of the mover **220** are regulated. The output transmission member **242** includes a protrusion part **241**, the protrusion part **241** fits with a fork connected with a cum ring **315**, and the cum ring **315** rotates together with rotation of the output transmission member **242**.

[0116] A key groove **317** is engraved in the cum ring **315** diagonally in the circumferential direction, a fixing pin **318** provided to an AF ring **319** fits to the key groove **317**, and, when the cum ring **315** is rotated and driven, the AF ring **319** is driven in the direction straight to the optical axis direction, and can stop at a desired position.

[0117] The retention ring **251** is attached to the fixing member **223** by a screw, and, by attaching this retention ring **251**, the output transmission member **242** to the mover **220**, the vibrator **211** and the pressurizing member **250** can be formed as one motor unit.

[0118] What is the same as embodiment 1 is that the vibration wave motor **210** which uses the vibrator **211** according to embodiment 2 also has a very little temperature characteristics of the consumption current compared to the PZT-mounted product. Furthermore, the impedance of the driving device 300 and the impedance of the vibration wave motor **210** are matched. A change in the electrostatic capacitance Cdv of the vibrator **10** of the vibration wave motor **210** according to embodiment 2 at the time of the low temperature and at the time of the high temperature is a little compared to the PZT-mounted product, so that it is possible to substantially make fluctuation of the drive voltage E a very little, and driving efficiency of the driving device 300 itself is improved. Furthermore, what is the same as embodiment 1 is that the electrostatic capacitance Cdv of the vibrator **10** is fluctuated little by an environmental temperature, and therefore a temperature change in a drivable voltage of the vibration wave motor **210** is also a little.

Embodiment 3

[0119] A vibration wave motor according to embodiment 3 is a type whose vibrator includes only the piezoelectric body **11**, and whose driving rail which is a relative motion member is linearly driven. The same components as those of embodiment 1 and embodiment 2 will be assigned the same reference numerals, and description thereof will be omitted.

[0120] FIG. **15** is an explanatory view illustrating the vibrator according to embodiment 3. FIG. **15**(A) is a front view and a back view of a vibrator **1500**, FIG. **15**(B) is a schematic perspective view of the vibrator **1500**, and FIG. **15**(C) is an explanatory view illustrating an implementation example of the vibrator **1500**.

[0121] The vibration wave motor **1** according to embodiment 3 is a type whose vibrator **1500** includes only the piezoelectric body **11**, and whose driving rail **1550** which is a relative motion member is linearly driven. The vibrator **1500** includes the piezoelectric body **11** made of the same sodium-potassium niobate metal oxides as those of embodiment 1, and sliding members **1560** which are installed at end parts.

[0122] The vibrator **1500** is pressurized against the driving rail **1550** by a pressurizing spring **1525**. A linear guide **1527** is provided between a fixing member **1513** and the driving rail **1550**, a linear guide fixing part **1527***a* is fixed to the fixing member **1513**, a movable part **1527***b* is coupled to the driving rail **1550**, and the driving rail **1550** can be moved only in left and right directions in the figure. An elliptical motion is produced at positions of sliding members **1560** of the vibrator **1500** to linearly drive the driving rail **1550**.

[0123] The vibrator **1500** adopts a two-layer structure, one electrode **1510** is provided on a first surface **1501** in a first layer, and one electrode **1520** having the same shape is provided on a second surface **1502** on an opposite side, too. An A phase drive signal is input to the electrode **1510** on the first surface **1501** side, and the electrode **1520** of the second surface **1502** is a GND. In response to the input of the A phase drive signal, the vibrator **1500** produces a standing wave of longitudinal primary mode vibration.

[0124] Four divided electrodes **1531** to **1534** are provided on a third surface **1503** in the second layer, and polarization directions of the four electrodes **1531** to **1534** are respectively alternate. One electrode **1540** having the same shape as that of the first layer is provided on a fourth surface **1504** on an opposite side, too. A B phase drive signal is input to the electrodes **1531** to **1534** on the third surface **1503** side, and the electrode **1540** on the fourth surface **1504** side is a GND. In response to the input of the B phase drive signal, the vibrator **1500** produces a standing wave of bending secondary mode vibration.

[0125] As for the first layer and the second layer, the second surface **1502** which is the GND in the first layer and the fourth surface **1504** which is the GND in the second layer are bonded to form a common GND. A groove part **1505** is provided at a center part of the vibrator **1500**, and the pressurizing spring **1525** fits this groove to prevent displacement of a pressurizing position, and support the driving rail **1550** in a longitudinal direction.

[0126] The sliding members **1560** are made of an engineer plastic material of good abrasion resistance, and are provided at places in the figure which are positions at which an amplitude of the standing wave of the longitudinal primary mode vibration maximizes and an amplitude of a standing wave of the bending secondary mode vibration maximizes.

<Operation Principal of Vibrator **1500**>

[0127] FIG. **16** is an explanatory view illustrating a driving principal of the vibrator **1500** according to embodiment 3. FIG. **16** (*a*) to (*e*) will be described in chronological order below. In graphs at left ends in FIG. **16** (*a*) to (*e*), t represents a time, a vertical axis indicates a voltage, and a horizontal axis indicates a time.

[0128] t=1: A voltage of the A phase is 0, and a voltage of the B phase is minus. In this case, displacement of the longitudinal primary vibration is zero, and the bending secondary vibration which displaces a C point in a minus direction and displaces a D point in a plus direction occurs.

[0129] t=2: The voltage of the A phase is plus, and the voltage of the B phase is 0. In this case, the longitudinal primary vibration which causes displacement in the plus direction occurs, and displacement of the bending secondary vibration is zero.

[0130] t=3: The voltage of the A phase is 0, and the voltage of the B phase is plus. In this case, displacement of the longitudinal primary vibration is zero, and the bending secondary vibration which displaces the C point in the plus direction and displaces the D point in the minus direction occurs.

[0131] t=4: The voltage of the A phase is plus, and the voltage of the B phase is 0. In this case, the longitudinal primary vibration which causes displacement in the minus direction occurs, and displacement of the bending secondary vibration is zero.

[0132] t=5: Return to a case of t=1. When vibration is caused in this way, elliptical motions occur at the C point and the D point at which the sliding members **1560** are attached as illustrated at a right end in FIG. **16**. When the mover is placed in pressure contact with these sliding members **1560**, the mover is applied a friction force of the elliptical motions and driven. According to embodiment 3, the same material as that of embodiment 1 is used for the piezoelectric body **11**, so that it is possible to obtain the same effect as that of embodiment 1.

Embodiment 4

[0133] Embodiment 4 describes an example where the vibration wave motor **1** is applied to a dust proof device including a camera. The same components as those of embodiment 1 will be assigned the same reference numerals, and description thereof will be omitted.
[0134] FIG. **17** is an explanatory view illustrating an example of the dust proof device according to embodiment 4. The dust proof device 1700 is installed near an imaging element **1701**, and vibration of the piezoelectric body **11** vibrates an optical filter **1702** to remove dust adhered to the optical filter **1702**. The dust proof device 1700 according to embodiment 4 also includes the piezoelectric body **11** and the driving device 300. A task that a voltage of driving vibration from the driving device 300 fluctuates depending on the value of the electrostatic capacitance Cd of the piezoelectric body **11** is the same as that of the vibrator **10** of the vibration wave motor **1**. According to embodiment 4, the same material as that of embodiment 1 is used for the piezoelectric body **11**, so that it is possible to obtain the same effect as that of embodiment 1.
[0135] The present invention is not limited to the content above, and the content above may be freely combined. Also, other aspects considered to be within the scope of the technical concept of the present invention are included in the scope of the present invention.
EXPLANATION OF REFERENCES
[0136] **1** vibration wave motor, **10** vibrator, **11** piezoelectric body, **12** elastic body, **12*a*** driving surfaces, **12*f*** bonding surface, **20** mover, **20*a*** sliding surface, **300** driving device, **110** lens barrel, **200** lens barrel, **210** vibration wave motor, **211** vibrator, **214** elastic body, **216*a*** driving surface, **220** mover, **1500** vibrator, **1700** dust proof device

Claims

1. A vibrator comprising an electromechanical transducer which is a piezoelectric ceramic made of sodium-potassium niobate metal oxides and whose temperature characteristics of a relative permittivity is 500 [ppm/° C.] or less in absolute value in a temperature range from −40° C. to 170° C., wherein excitation of the electromechanical transducer produces a vibration wave.