US 20240410350A1

(19) **United States**

(12) **Patent Application Publication** (10) **Pub. No.: US 2024/0410350 A1**

Tanaka et al. (43) **Pub. Date: Dec. 12, 2024**

(54) **MICRO DIAPHRAGM PUMP**

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(21) Appl. No.: **18/699,720**

(22) PCT Filed: **Dec. 6, 2021**

(86) PCT No.: **PCT/JP2021/044691**

§ 371 (c)(1),
(2) Date: **Apr. 9, 2024**

Publication Classification

(51) **Int. Cl.**
F04B 43/04 (2006.01)

(52) **U.S. Cl.**
CPC ***F04B 43/043*** (2013.01)

(57) **ABSTRACT**

A micro-diaphragm pump includes a main body, a pump chamber, a diaphragm, a first electrode and a second electrode. The diaphragm is constituted of a crystal material having an electrostrictive effect. The diaphragm can be constituted of a transparent crystal material having an electrostrictive effect. The diaphragm can be constituted of either a cubic KTN [$KTa_{1-\alpha}Nb_{\alpha}O_3$ ($0<\alpha<1$)] crystal or a lithium-added cubic KLTN [$K_{1-\beta}Li_{\beta}Ta_{1-\alpha}Nb_{\alpha}O_3$ ($0<\alpha<1$, $0<\beta<1$)] crystal.

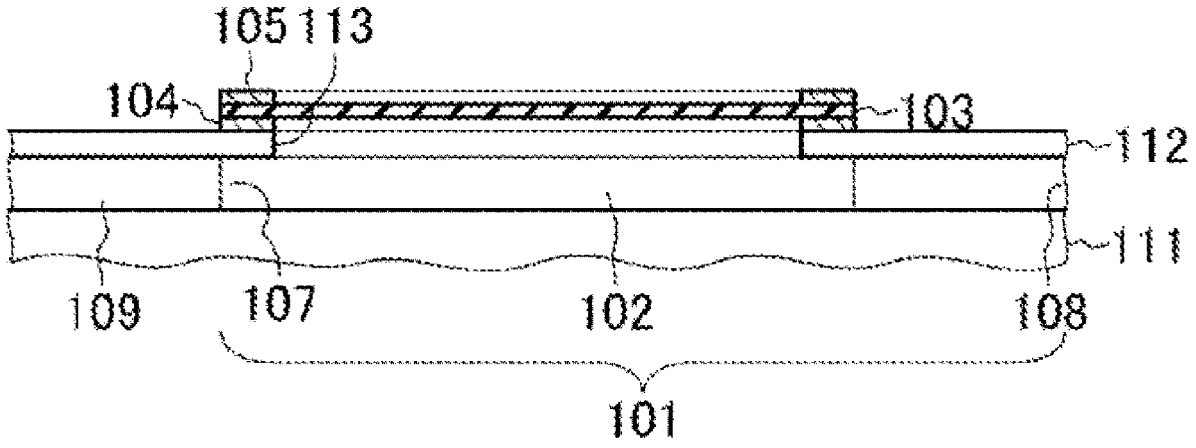


Fig. 1A

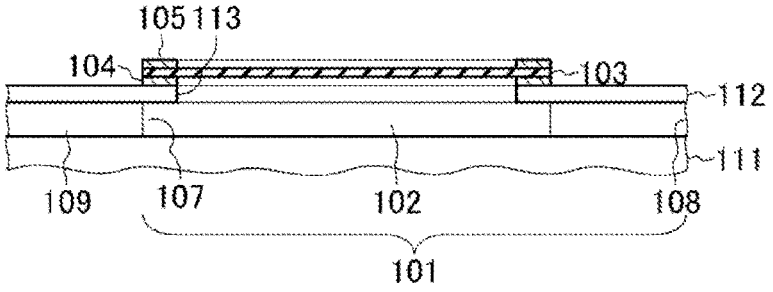


Fig. 1B

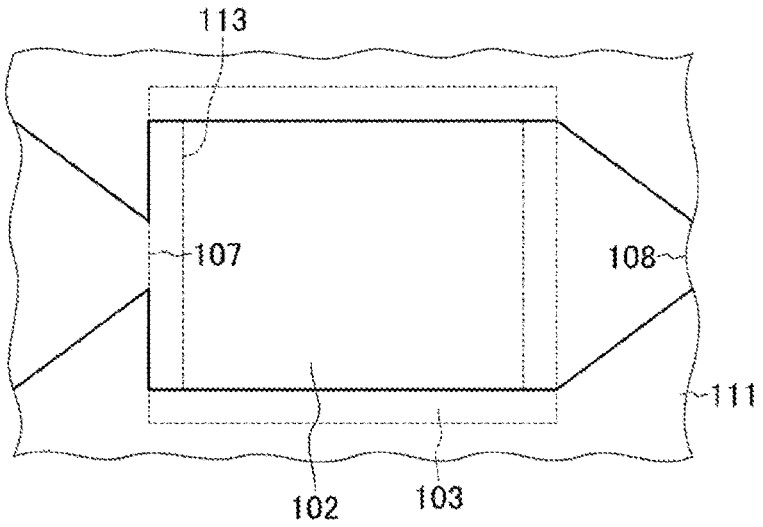
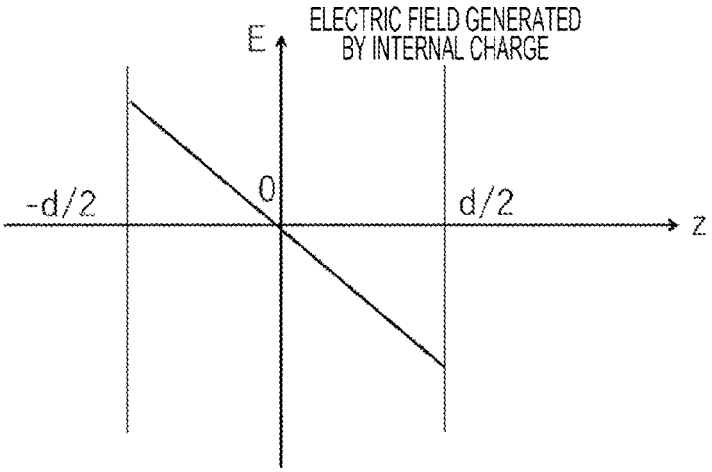
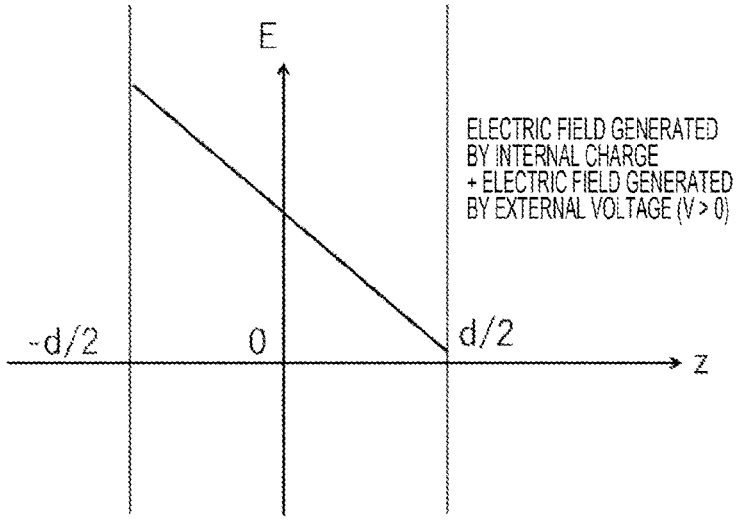


Fig. 2A



$$E_{z(in)}(z) = \frac{\rho}{\varepsilon_0 \varepsilon_r} z$$

Fig. 2B



$$E_z(z) = \frac{\rho}{\varepsilon_0 \varepsilon_r} z + \frac{V}{d}$$

Fig. 3

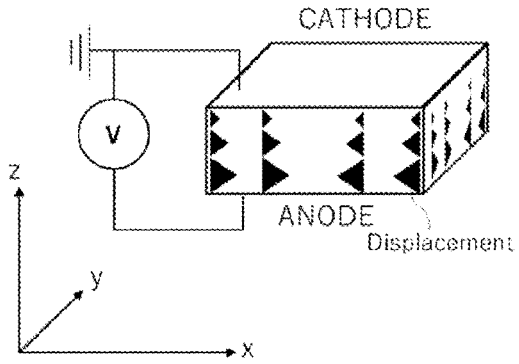


Fig. 4

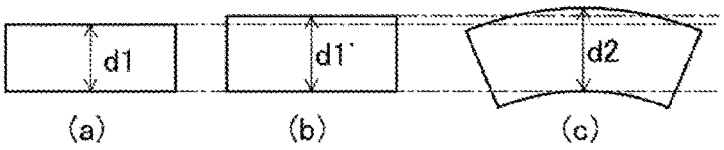


Fig. 5

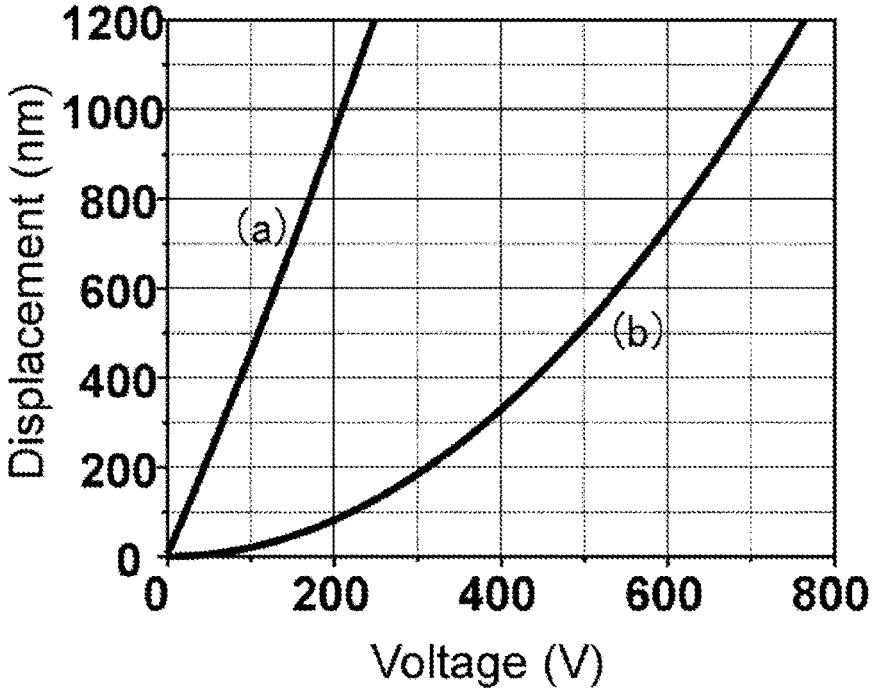

1200
1000
800
600
400
200
0
Displacement (nm)
(a)
(b)
0
200
400
600
800
Voltage (V)

Fig. 6A

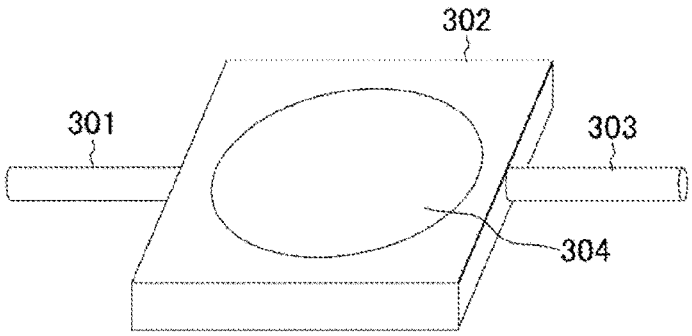


Fig. 6B

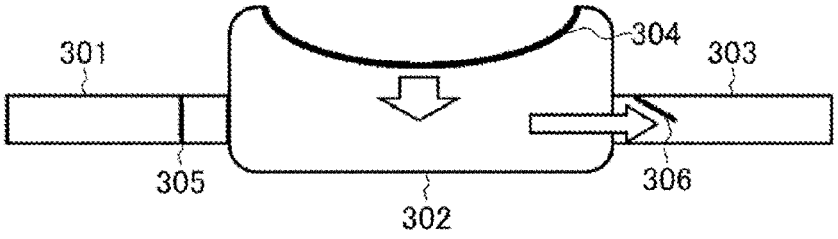


Fig. 6C

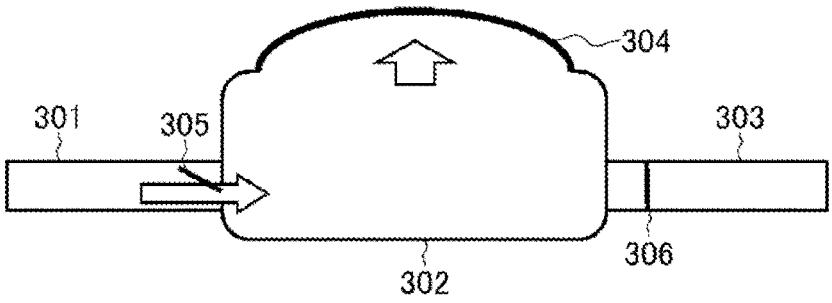


Fig. 7A

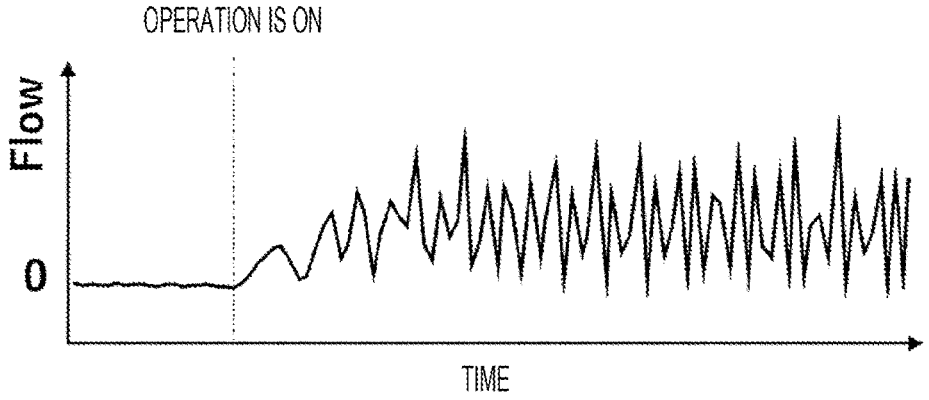
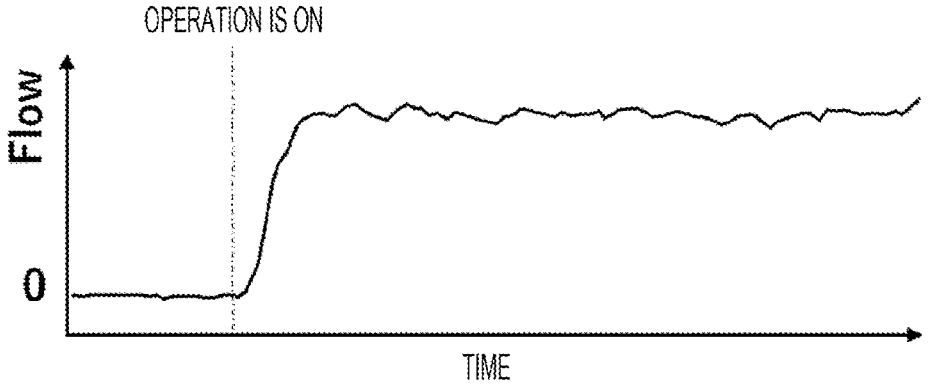


Fig. 7B



MICRO DIAPHRAGM PUMP

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is a national phase entry of PCT Application No. PCT/JP2021/044691, filed on Dec. 6, 2021, which application is hereby incorporated herein by reference.

TECHNICAL FIELD

[0002] The present invention relates to a micro-diaphragm pump.

BACKGROUND

[0003] In the fields of biotechnology and medicine, development of a micropump has been actively progressed for the purpose of enabling analysis of a small amount of sample and enabling precise control of the amount of sample, the amount of reagent, and the like. Also in the development of chemical analysis devices called micro TAS(Micro Total Analysis Systems: μ-TAS) that perform mixing, reaction, separation, analysis, and the like in a chip, there is an increasing expectation for higher performance of micropumps. Due to miniaturization of various components, device integration technology has also advanced, and high performance of micropumps is also important in the development of a healthcare terminal or a bedside clinical examination apparatus.

[0004] Here, an operation principle of a general diaphragm pump will be described (refer to FIG. **6**A, FIG. **6**B, and FIG. **6**C). In the simplest configuration, the diaphragm pump includes a suction port **301**, a pump main body **302**, and a discharge port **303**. The pump main body **302** includes a diaphragm **304**. A gas or liquid is taken in from the suction port **301** by volume change of the pump main body **302** due to deformation of the diaphragm **304**, and the gas or liquid taken in is discharged from the discharge port **303** according to the volume change.

[0005] A suction valve **305** and a discharge valve **306** are generally provided at the suction port **301** and the discharge port **303** respectively so as to easily control the flow of the gas or liquid according to the volume change. The volume change of the pump main body **302** caused by the vibration of the diaphragm (partition wall) **304** is induced so that the gas or liquid flows from the suction port toward the discharge port, thereby realizing the function as a pump.

[0006] In the micro-diaphragm pump, various contrivances have been made in order to make each part literally smaller. A micro-diaphragm pump that is already commercially available adopts a valveless design capable of controlling a flow direction of the gas or liquid in the pump by miniaturizing a component corresponding to a diaphragm using a piezoelectric material or MEMS (Micro Electro Mechanical Systems), even in a structure which does not have a suction/discharge valve whose response speed is difficult to follow (Non-Patent Literature 1).

[0007] Thus, micropumps are being studied to eliminate mechanism by adopting piezoelectric materials, MEMS, and structures without valves. On the other hand, the following problems have been revealed. First, a pump using a piezoelectric material has a low response speed and is likely to cause pulsation (=loss of pump driving). In addition, a pump using MEMS has a short life.

[0008] Here, pulsation will be described. In a pump using a general diaphragm, a gas or liquid is drawn into a pump main body from a suction port according to a contraction (distortion) of the diaphragm, and is discharged from a discharge port. When the diaphragm contracts at a high speed, a phenomenon, in which the valves cannot respond or a loss occurs in the suction pressure or the discharge pressure and the discharge flow rate is not constant, appears as pulsation as shown in FIG. **7**A. It is known that the pulsation is likely to cause a loss in a gas having a low contact resistance with a suction port, a discharge port, or the like. A state without pulsation is shown in FIG. **7**B.

CITATION LIST

Non Patent Literature

[0009] Non Patent Literature 1: Ryuta Ikoma et al., "Fabrication of a valveless micropump with polyimide membrane", Heisei 22, College of Science and Technology of Nihon University, Proceedings of the Academic Conference, Vol. 54, K6-11, pages 759 to 760, 2010.

SUMMARY

Technical Problem

[0010] In order to suppress pulsation, measures such as a design capable of sufficiently ensuring the differential pressure between the suction port and the discharge port and a further high-speed operation of the pump are generally used, and improvement of the response speed of the piezoelectric material is a problem.

[0011] In a micro-diaphragm pump using MEMS, there are problems of partial wear due to repeated contraction of a semiconductor device which is made of a MEMS material, and of wear failure due to a pressure load applied to the MEMS itself by flowing gas or liquid. In order to improve the life of the micro-diaphragm pump using MEMS, it is necessary to increase the mechanical strength by increasing the size and the thickness of the contracting portion and to review the material to be used. However, such a countermeasure has a trade-off with other characteristics, making the problem difficult. Thus, conventionally, there has been a problem that it is not easy to achieve the high performance of a tiny micro-diaphragm pump.

[0012] Embodiments of the present invention have been made to solve the above problems, and an object thereof is to achieve the high performance of a tiny micro-diaphragm pump.

Solution to Problem

[0013] The micro-diaphragm pump according to embodiments of the present invention includes: a main body that forms a concave portion; a diaphragm that is constituted of a crystal material having an electrostrictive effect, the diaphragm covering an opening of the concave portion and defining a pump chamber together with the main body; a first electrode that is ohmically connected to one surface of the diaphragm; and a second electrode that is ohmically connected to another surface of the diaphragm.

Advantageous Effects of Embodiments of Invention

[0014] As described above, according to embodiments of the present invention, the diaphragm is constituted of the

crystal material having the electrostrictive effect, the first electrode is ohmically connected to one surface of the diaphragm, and the second electrode is ohmically connected to the other surface of the diaphragm, and thus, it is possible to realize high performance of a tiny micro-diaphragm pump.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] FIG. **1**A is a cross-sectional view showing a configuration of a micro-diaphragm pump according to an embodiment of the present invention.

[0016] FIG. **1**B is a plan view showing a partial configuration of the micro-diaphragm pump according to the embodiment of the present invention.

[0017] FIG. **2**A is a characteristic diagram showing a relation between a position of a KTN crystal in a direction perpendicular to an electrode surface and an electric field generated by an internal charge.

[0018] FIG. **2**B is a characteristic diagram showing a relation between the position of the KTN crystal in the direction perpendicular to the electrode surface and an electric field in a case when an electric field generated by an external voltage is added to the electric field generated by the internal charge.

[0019] FIG. **3** is an explanatory diagram for explaining a relation between crystal contraction amounts in an x direction and a y direction and a position z of the KTN crystal where the electric field generated by the internal charge is added to the electric field generated by the external voltage.

[0020] FIG. **4** is an explanatory diagram for explaining a distortion change of the KTN crystal in a case where there is a warp due to charge injection and in a case where there is no warp due to charge injection.

[0021] FIG. **5** is a characteristic diagram showing a difference in displacement of the KTN crystal between a case (a) where charge injection is performed and a case (b) where charge injection is not performed.

[0022] FIG. **6**A is a perspective view showing a configuration of a diaphragm pump.

[0023] FIG. **6**B is a cross-sectional view showing the configuration of the diaphragm pump.

[0024] FIG. **6**C is a cross-sectional view showing the configuration of the diaphragm pump.

[0025] FIG. **7**A is a characteristic diagram showing a state of pulsation in which a discharge flow rate of the diaphragm pump is not constant.

[0026] FIG. **7**B is a characteristic diagram showing a state in which there is no pulsation in the discharge flow rate of the diaphragm pump.

DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

[0027] Hereinafter, a micro-diaphragm pump according to an embodiment of the present invention will be described with reference to FIG. **1**A and FIG. **1**B. The micro-diaphragm pump includes a main body **101** that forms a concave portion, a diaphragm **103** that covers an opening of the concave portion and defines a pump chamber **102** together with the main body **101**, a first electrode **104**, and a second electrode **105**. For example, the first electrode **104** can be an anode electrode and the second electrode **105** can be a cathode electrode.

[0028] The diaphragm **103** is constituted of a crystal material having an electrostrictive effect. The diaphragm **103** can be constituted of a transparent crystal material having an electrostrictive effect. The diaphragm **103** can be constituted of either a cubic KTN [$KTa_{1-\alpha}Nb_{\alpha}O_3$ $(0<\alpha<1)$] crystal or a lithium-added cubic KLTN [$K_{1-\beta}Li_{\beta}Ta_{1-\alpha}Nb_{\alpha}O_3$ $(0<\alpha<1,\ 0<\beta<1)$] crystal.

[0029] The first electrode **104** is ohmically connected to one surface of the diaphragm **103**, and the second electrode **105** is ohmically connected to the other surface of the diaphragm **103**. For example, the first electrode **104** and the second electrode **105** may have a laminated structure of a metal such as titanium or nickel and a metal such as platinum or gold Au. For example, the first electrode **104** and the second electrode **105** can be formed by depositing a metal such as titanium or nickel at each electrode formation location by vapor deposition or the like, and then depositing a metal such as platinum or gold Au at each electrode formation location by vapor deposition or the like. The first electrode **104** and the second electrode **105** formed in this manner can be ohmically connected to the diaphragm **103**.

[0030] In addition, after the electrode metal material is deposited at each electrode formation location by vapor deposition or the like, by performing heat treatment (for example, 400° C./min), it is possible to adjust the ohmic resistance between the deposited metal material and the diaphragm **103** and perform ohmic connection.

[0031] The voltage application in the plate thickness direction of the diaphragm **103** and the charge injection into the diaphragm **103** are performed by the first electrode **104** and the second electrode **105**. The first electrode **104** and the second electrode **105** can be formed around the diaphragm **103** except for the central portion of the diaphragm **103**. With this configuration, the diaphragm **103** is constituted of a transparent material, and thus, the fluid flowing through the pump chamber **102** can be optically observed from the outside. In addition, by constituting each electrode of a multilayer film which is made of a material such as tin or indium to be transparent at a target wavelength, it is possible to realize a configuration in which the inside of the pump chamber **102** can be observed.

[0032] For example, the main body **101** can include a substrate **11** made of a single-crystal Si and an upper plate **112** made of a single-crystal Si fixed on the substrate **11**. The upper plate **112** includes an opening **113** at a position of the concave portion, which serves as the pump chamber **102**, of the substrate **11**. The diaphragm **103** is formed so as to close the opening **113** of the upper plate **112**. In the pump chamber **102**, for example, the distance (interval) between the bottom surface and the diaphragm **103** serving as the ceiling can be about 50 μm, the width can be 200 μm in a plan view, and the depth can be 3000 μm in the flow path direction.

[0033] The first electrode **104** is formed on the upper surface of the upper plate **112** around the opening **113**, and the first electrode **104** is interposed between the upper plate **112** and the peripheral portion of the diaphragm **103**. Further, the second electrode **105** is formed at a position facing the first electrode **104** with the diaphragm **103** interposed therebetween. Here, by forming the diaphragm **103** in a shape recessed toward the pump chamber **102** in an initial state, the second electrode **105** can be easily formed on the diaphragm **103**.

[0034] The micro-diaphragm pump also includes a suction port **107** formed in the pump chamber **102** and configured to

suck a target fluid into the pump chamber **102**, and a discharge port **108** formed in the pump chamber **102** for pushing out the fluid from the pump chamber **102**. In the pump chamber **102**, the size of a cross section perpendicular to the transfer direction is reduced toward the discharge port **108**. For example, the width of the pump chamber **102** in a plan view can be 200 μm, and the opening width of the discharge port **108** can be 50 μm. With this configuration, the discharge pressure at the discharge port **108** can be made smaller than the discharge pressure at the suction port **107**.

[0035] A flow path **109** is connected to the suction port **107**. In the flow path **109**, the size of the cross section perpendicular to the transfer direction is reduced toward the suction port **107**. For example, the width of the pump chamber **102** in a plan view can be 200 μm, and the opening width of the suction port **107** can be 50 μm. With this configuration, backflow from the pump chamber **102** side to the suction port **107** side is less likely to occur.

[0036] In the above-described embodiment, the first electrode **104** and the second electrode **105** are ohmically connected to the diaphragm **103**, and thus, it is possible to realize the voltage application in the plate thickness direction of the diaphragm **103** and the charge injection into the diaphragm **103**.

[0037] In order to suppress the pulsation of the micro-diaphragm pump, the diaphragm **103** is constituted of a crystal material having an electrostrictive effect, such as KTN, which can be expected to have a high-speed response in the order of MHz. In general, the electrostrictive effect is smaller than the piezoelectric effect, and it is considered disadvantageous to use a crystal material such as KTN exhibiting electrostrictive characteristics for the diaphragm **103**.

[0038] However, by ohmically connecting the first electrode **104** and the second electrode **105** to the diaphragm **103**, it is more likely to induce the charge injection into the diaphragm **103** and create an electric field gradient in the crystal of the diaphragm **103**, thereby distributing the electrostrictive effect according to the distances from the electrodes, and thus, it is possible to use the warping of the diaphragm **103** to develop a large shape change. Furthermore, by applying a voltage signal in which a DC voltage and an AC voltage are superimposed on each other to the diaphragm **103**, it is possible to selectively use a case where the diaphragm **103** repeatedly becomes concave and convex, a case where the diaphragm **103** deforms into a convex shape only on one side, and the like, and it is possible to expect precise flow rate control and reduction of a load on the diaphragm **103** and the like.

[0039] For example, the KTN crystal is a cubic crystal, and an electrostrictive effect occurs when an electric field is present inside the crystal. This electrostrictive effect will be described using the KTN crystal as an example. As described in Reference Literature 1, electrodes are formed on the KTN crystal and a voltage is applied to the KTN crystal to generate an electrostrictive effect, and the KTN crystal is displaced so as to extend in the electric field direction and contract in a direction perpendicular to the electric field. The strain caused by the electrostrictive effect is expressed as in the expression shown below, where e represents the strain, Q represents the electrostrictive coefficient, and P represents the polarization.

$$[e] = [Q][PP] \qquad \text{Equation 1}$$

$$[e] = \begin{bmatrix} e_{xx} \\ e_{yy} \\ e_{zz} \\ e_{yz} \\ e_{zx} \\ e_{xy} \end{bmatrix}, [Q] = \begin{bmatrix} Q_{11} & Q_{12} & Q_{12} & 0 & 0 & 0 \\ Q_{12} & Q_{11} & Q_{12} & 0 & 0 & 0 \\ Q_{12} & Q_{12} & Q_{11} & 0 & 0 & 0 \\ 0 & 0 & 0 & Q_{44} & 0 & 0 \\ 0 & 0 & 0 & 0 & Q_{44} & 0 \\ 0 & 0 & 0 & 0 & 0 & Q_{44} \end{bmatrix}, [PP] = \begin{bmatrix} P_xP_x \\ P_yP_y \\ P_zP_z \\ P_yP_z \\ P_zP_x \\ P_xP_y \end{bmatrix}$$

[0040] A polarization P is proportional to an electric field E in the above-described expression. In the state when the internal charge of the KTN crystal is 0 C/m_3, the electric field E due to the external voltage is expressed as E=V/d, where V (>0) represents the voltage, and d represents the interelectrode distance. Accordingly, the electric field is inversely proportional to the interelectrode distance, and thus, shortening the interelectrode distance contributes to a decrease in the drive voltage.

[0041] As described above, this electrostrictive effect is a phenomenon that occurs only when the KTN crystal is a cubic crystal. The crystal structure of the KTN crystal depends on the temperature, and the KTN crystal becomes a cubic crystal when the temperature is at or above the Curie temperature. Also, the KTN crystal is used with the relative permittivity εr of the KTN crystal being above 10,000, and thus, the polarization P can be regarded as being proportional to the relative permittivity εr. Since the relative permittivity εr has temperature dependence, temperature control is also important in stably generating the electrostrictive effect.

[0042] Further, as described in Reference Literature 2, in a case where electrodes are in ohmic contact, when a high voltage is applied between the electrodes, electrons are injected into the KTN crystal. Where d represents the interelectrode distance, co represents the dielectric constant of vacuum, εr represents the relative permittivity, p represents the electron density, z represents the direction perpendicular to the electrode surface, the anode is at the position expressed as z=−d/2, and the cathode is at the position expressed as z=d/2, the electric field generated by the internal charge is expressed as in the expression shown below according to Gauss's law.

$$E_{z(in)}(z) = \frac{\rho}{\varepsilon_0 \varepsilon_r} z \qquad \text{Equation 2}$$

[0043] In the case of the KTN crystal, electrons are injected as internal charges, and therefore, p has a negative value. Therefore, the relation between the position z and the electric field Ez(in) in the direction perpendicular to the electrode surface is a linear expression of z with a negative gradient (FIG. **2**A). When an external voltage is applied, an electric field generated by the external voltage is also added to the above expression, and therefore, the electric field Ez to be applied to the KTN crystal is as shown below.

$$E_z = \frac{\rho}{\varepsilon_0 \varepsilon_r} z + \frac{\mathrm{V}}{d} \qquad \text{Equation 3}$$

[0044] Accordingly, as can be seen from FIG. **2**B, the magnitude of the electric field in the vicinity of the anode (z=−d/2) is greater than the magnitude of the electric field in the vicinity of the cathode (z=d/2).

[0045] Further, since the relative permittivity εr of KTN satisfies 1<<εr, the polarization Pz satisfies the relationship shown below.

$$P_z \sim \varepsilon_0 \varepsilon_r E_z \qquad \text{Equation 4}$$

[0046] Where Ex=Ey=0, Px=Py=0, and exx, eyy, and ezz can be written as follows.

$$e_{xx} = Q_{12} P_z^2 \sim Q_{12} (\varepsilon_0 \varepsilon_r)^2 E_z^2 \qquad \text{Equation 5}$$

$$e_{yy} = Q_{12} P_z^2 \sim Q_{12} (\varepsilon_0 \varepsilon_r)^2 E_z^2$$

$$e_{zz} = Q_{11} P_z^2 \sim Q_{11} (\varepsilon_0 \varepsilon_r)^2 E_z^2$$

[0047] Here, Q11 >0, and Q12<0. Therefore, it is apparent that the crystal expands in the Z-axis direction (the plate thickness direction), and the crystal contracts in the X-axis direction and the Y-axis direction. Further, in a case where the relation shown in the expression below is satisfied, ezz monotonically decreases in the Z-axis direction. That is, the magnitude of the strain on the cathode side is small, and the magnitude of the strain on the anode side is large.

$$\left| \frac{\rho}{\varepsilon_0 \varepsilon_r} \frac{d}{2} \right| \leq \frac{\mathrm{V}}{d} \qquad \text{Equation 6}$$

[0048] In view of the above, the crystal contraction amounts in the x direction and the y direction vary depending on the position z, as shown in FIG. **3**. As a result, warpage that protrudes toward the cathode side occurs in the crystal.

[0049] In a state where the applied voltage is 0 V, the center position of the surface of the KTN crystal on the cathode side (diaphragm **103**) is at the position expressed as z=0, and the gravity center position of the crystal surface on the cathode side in a state where the voltage is applied is at the position expressed as z=Δz. Δz will hereinafter be referred to as displacement. Crystals with and without warpage due to charge injection will be described with reference to FIG. **4**.

[0050] d1(a) represents the distance from the gravity center of the lower surface to the gravity center of the upper surface of the KTN crystal when no voltage is applied, d1'(b) represents the distance from the gravity center of the lower surface to the gravity center of the upper surface of the KTN crystal when there is no internal charge and a voltage is applied, and d2(c) represents the distance from the gravity center of the lower surface to the gravity center of the upper surface of the KTN crystal when there is an internal charge and a voltage is applied.

[0051] The relation among these distances is expressed as d1<d1'<d2. It has been confirmed based on experiments that the KTN crystal warps due to charge injection and that a large displacement is obtained due to deformation of the KTN crystal (FIG. **5**). In FIG. **5**, (a) shows a case where there is charge injection, and (b) shows a case where there is no charge injection.

[0052] In the micro-diaphragm pump according to the above-described embodiment, for example, when the cathode electrode (the second electrode **105**) is fixed to the ground level and the potential of the anode electrode (the first electrode **104**) is driven in a range from 0 V to 100 V inclusive, the volume of the pump chamber **102** increases at 100 V as compared with the state at 0 V. In this state, a gas or liquid is taken into the pump chamber **102** from the suction port **107** due to a pressure difference between the suction port **107** and the discharge port **108** viewed from the pump chamber **102**.

[0053] Next, when the potential of the anode electrode is lowered from 100 V to 0 V, the distortion of the diaphragm **103** is eliminated, the volume of the pump chamber **102** becomes the initial state, and the gas or liquid drawn into the pump chamber **102** is discharged to the outside of the pump chamber **102**. In this state, a large amount of the gas or liquid is discharged from the discharge port **108** having a discharge resistance smaller than that of the suction port **107**. Thus, by controlling and operating the voltage signal applied to the diaphragm **103**, it is possible to drive the diaphragm as a diaphragm pump.

[0054] In controlling the voltage applied to the diaphragm **103**, it is not always necessary to fix either the cathode electrode or the anode electrode to the ground potential. For example, it is also possible to control the voltage signal so that the diaphragm **103** is distorted in a manner of displacing in both directions toward the cathode side and the anode side, thereby increasing the displacement amount of the inner volume of the pump chamber **102**.

[0055] The diaphragm **103** constituted of KTN can respond at a high speed of about 1 MHz, and can be controlled at a speed higher than the generally used response speed (several tens of kHz to 100 kHz inclusive) based on the piezoelectric effect. By controlling the operation of the diaphragm **103** at a high speed, it is possible to suppress pulsation which is a problem in a diaphragm pump without a mechanical valve and to more precisely control the flow rate of the gas or liquid. This is considered to be particularly advantageous in the flow rate control of targets such as gases, for example, which have low frictional resistance against the inner walls of the pump chamber **102** or the like, in other words, which lead to a large loss of pump efficiency due to fluid returning to the side of the suction port **107** and thus lead to a large pump loss. Here, in order to operate the diaphragm **103** constituted of KTN at a high speed, it is important to reduce the electrostatic capacitance of the diaphragm **103**. For example, it is important to design the electrodes to configure the electrodes only in the portion covering the pump chamber **102** and to suppress the electrostatic capacitance in the unnecessary portions of the diaphragm **103**.

[0056] The KTN crystal is used in a temperature range in which it is a cubic crystal, and the cubic KTN crystal is colorless and transparent (Reference Literature 3). For example, by providing a portion through which light passes in a part of the electrode of the diaphragm **103** constituted of KTN or by constituting the electrode of a transparent material, it is possible to apply light to the portion of the pump chamber **102** or to detect the reflected light from the pump chamber **102**. Such an optical method enables com-

ponent analysis of the gas or liquid passing through the pump chamber **102**, monitoring of foreign matter contained in the gas or liquid, detection of density change of the gas or liquid, and the like. Thus, according to the embodiment, the micro-diaphragm pump can be used, for example, to configure a μ-TAS which has a pump function and can be applied as a biomedical device.

[0057] There may be a case where the diaphragm **103** is dissolved in a fluid to be transferred (transported) or chemically reacts with the fluid or a substance in the fluid and thus deteriorates. In such a case, a protective film for protecting the diaphragm **103** from the fluid can be further provided on the surface of the diaphragm **103** on the pump chamber **102** side. For example, it is preferable to form a protective film for protecting the diaphragm **103** at a portion where the diaphragm **103** is in contact with the fluid. The protective film can be constituted of a substance that does not dissolve in the fluid to be transported or does not react with the fluid or the substance in the fluid. By forming the protective film, deterioration of the diaphragm **103** can be prevented. For the purpose of preventing the fluid from staying on the surface of the diaphragm **103**, a protective film can be formed on the surface of the diaphragm **103** or on the electrode surface on the inner side of the diaphragm **103**.

[0058] As described above, according to embodiments of the present invention, the diaphragm is constituted of the crystal material having the electrostrictive effect, the first electrode is ohmically connected to one surface of the diaphragm, and the second electrode is ohmically connected to the other surface of the diaphragm, and thus, it is possible to realize high performance of a tiny micro-diaphragm pump.

[0059] Note that the present invention is not limited to the embodiment described above, and it is obvious that many modifications and combinations can be made by those skilled in the art within the technical idea of the present invention.

[0060] Reference Literature 1 S. Kawamura et al., "Temperature independent electrostrictive coefficients of K0.95Li0.05Ta0.73Nb0.27O3 single crystals", Journal of Applied Physics, vol. 122, 114101, 2017.

[0061] Reference Literature 2 T. Imai et al., "Anomalous index modulations in electrooptic KTa1-xNbxO3 single crystals in relation to electrostrictive effect", Optics Express, vol. 23, no. 22, pp. 28784-28791, 2015.

[0062] Reference Literature 3 Leading-Edge Key Technology Product Information, "Electro-Optical Crystals KTN (KTa1-xNbxO3)", [Searched on Nov. 19, 2021], (https://keytech.ntt-at.co.jp/ktn_crystal/prd_2044.html).

REFERENCE SIGNS LIST

[0063] **101** Main body
[0064] **102** Pump chamber
[0065] **103** Diaphragm
[0066] **104** First electrode
[0067] **105** Second electrode
[0068] **107** Suction port
[0069] **108** Discharge port
[0070] **109** Flow path
[0071] **11** Substrate
[0072] **112** Upper plate
[0073] **113** Opening

1-8. (canceled)

9. A micro-diaphragm pump comprising:

a main body that provides a concave portion;

a diaphragm that is constituted of a crystal material having an electrostrictive effect, the diaphragm covering an opening of the concave portion and defining a pump chamber together with the main body;

a first electrode that is ohmically connected to a first surface of the diaphragm; and

a second electrode that is ohmically connected to a second surface of the diaphragm.

10. The micro-diaphragm pump according to claim **9**, wherein in an initial state, the diaphragm is configured to be recessed towards the pump chamber.

11. The micro-diaphragm pump according to claim **9**, further comprising:

a suction port in the pump chamber and configured to suck a target fluid into the pump chamber; and

a discharge port in the pump chamber and configured to push out the target fluid from the pump chamber.

12. The micro-diaphragm pump according to claim **11**, wherein a size of a cross section of the pump chamber decreases towards the discharge port, the cross section of the pump chamber being perpendicular to a transfer direction of the target fluid.

13. The micro-diaphragm pump according to claim **11**, further comprising a flow path connected to the suction port, wherein a size of a cross section of the flow path decreases towards the suction port, the cross section of the flow path being perpendicular to a transfer direction of the target fluid.

14. The micro-diaphragm pump according to claim **9**, wherein:

the crystal material of the diaphragm is transparent and has the electrostrictive effect; and

the first electrode and the second electrode are formed around the diaphragm except for a central portion of the diaphragm.

15. The micro-diaphragm pump according to claim **9**, wherein the crystal material of the diaphragm is a KTN [$KTa_{1-\alpha}Nb_{\alpha}O_3$ $(0<\alpha<1)$] crystal.

16. The micro-diaphragm pump according to claim **9**, wherein the crystal material of the diaphragm is a KLTN [$K_{1-\beta}Li_{\beta}Ta_{1-\alpha}Nb_{\alpha}O_3$ $(0<\alpha<1,\ 0<\beta<1)$] crystal that comprises lithium.

17. The micro-diaphragm pump according to claim **9**, further comprising:

a protective film on a surface of the diaphragm on a side of the pump chamber, wherein the protective film is configured to protect the diaphragm from a target fluid.

18. A micro-diaphragm pump comprising:

a substrate;

an upper plate on a top surface of the substrate, the upper plate comprising an opening disposed therein;

a diaphragm that is constituted of a crystal material having an electrostrictive effect, the diaphragm covering an opening of the upper plate;

a first electrode that is ohmically connected to the diaphragm; and

a second electrode that is ohmically connected to the diaphragm, wherein the first electrode and the second electrode on disposed on opposing surfaces of the diaphragm.

19. The micro-diaphragm pump according to claim **18**, wherein in an initial state, the diaphragm is configured to be recessed in the opening.

20. The micro-diaphragm pump according to claim **18**, wherein the second electrode is disposed between the upper plate and the diaphragm.

21. The micro-diaphragm pump according to claim **18**, further comprising:

a suction port in the opening and configured to suck a target fluid into the opening; and

a discharge port in the opening and configured to push out the target fluid from the opening.

22. The micro-diaphragm pump according to claim **21**, wherein a size of a cross section of the opening decreases towards the discharge port.

23. The micro-diaphragm pump according to claim **21**, further comprising a flow path connected to the suction port, wherein a size of a cross section of the flow path decreases towards the suction port.

24. The micro-diaphragm pump according to claim **18**, wherein the crystal material of the diaphragm is transparent.

25. The micro-diaphragm pump according to claim **18**, wherein the crystal material of the diaphragm is a KTN [$KTa_{1-\alpha}Nb_{\alpha}O_3$ ($0<\alpha<1$)] crystal.

26. The micro-diaphragm pump according to claim **18**, wherein the crystal material of the diaphragm is a KLTN [$K_{1-\beta}Li_{\beta}Ta_{1-\alpha}Nb_{\alpha}O_3$ ($0<\alpha<1$, $0<\beta<1$)] crystal that comprises lithium.

27. The micro-diaphragm pump according to claim **18**, further comprising:

a protective film on a surface of the diaphragm on a side of the opening, wherein the protective film is configured to protect the diaphragm from a target fluid.

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