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TRANSDUCING DEVICE HAVING AN ELECTROMECHANICALLY
RESPONSIVE DIELECTRIC ELEMENT
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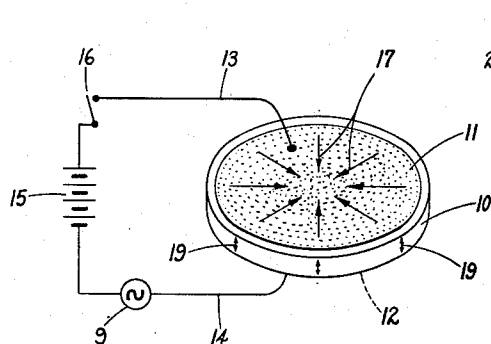


FIG. 1

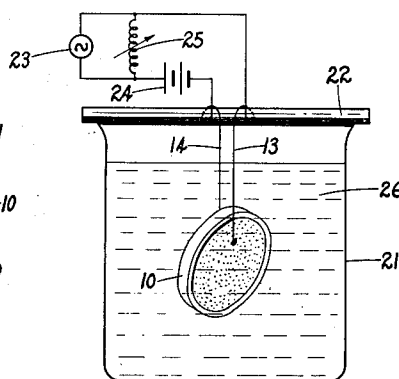


FIG. 2

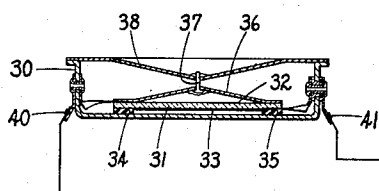


FIG. 3

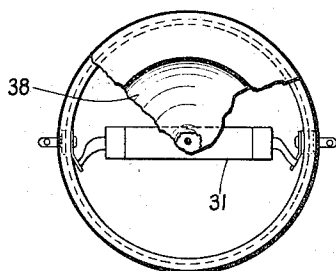


FIG. 4

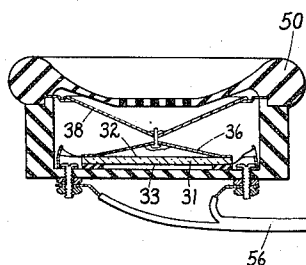
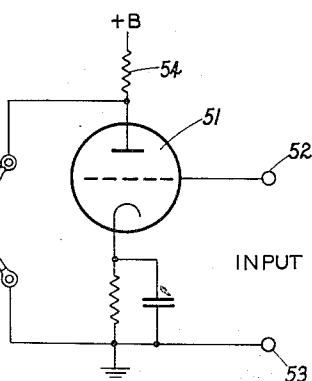
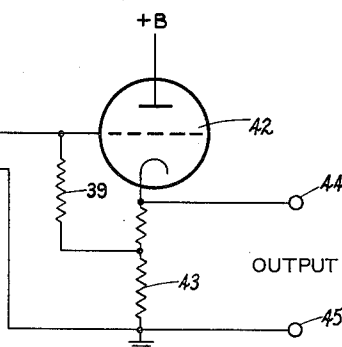


FIG. 5



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2,592,703

TRANSDUCING DEVICE HAVING AN ELECTROMECHANICALLY RESPONSIVE DIELECTRIC ELEMENT

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10 Claims. (Cl. 171-327)

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This invention relates to electromechanical transducers of the general type in which mechanical action results from the application of an electric field thereto and vice versa. More particularly, it relates to an improved electromechanical transducer which includes an operating element of a dielectric material polarized to respond substantially linearly as a first order effect to the energy input thereto.

Electromechanical transducers of the piezoelectric type are well known in the art. One such arrangement has comprised Rochelle salt as the operating element thereof and transducers of this type are widely used commercially. However, the properties of Rochelle salt are such that transducers comprising this material as an operating element do not provide entirely satisfactory operation under some operating conditions. For example, the temperature of such a unit must be maintained at all times below a rather low maximum value or, otherwise, the piezoelectric properties of the operating element are destroyed. Also, it is well known that such operating elements are somewhat fragile and, inasmuch as Rochelle salt is soluble in water, it is necessary in transducers of the type under consideration to insure that the operating properties of the unit are not adversely affected by humidity conditions.

It has been known that dielectric materials other than single asymmetric crystals have the property of expanding and contracting when subjected to an electric field and, for this reason, some attention has been given to the possible use of such materials as the operating element of electromechanical transducers of the general type here under consideration. However, in general, such dielectric materials have a very small response and in addition do not have the property of responding substantially linearly as a first order effect to the signal input thereto and this characteristic is, of course, undesirable in many applications of electromechanical transducers. I have discovered, however, that under certain conditions it is possible to polarize a dielectric material so that, as a first order effect, a transducer of this composition responds mechanically to the fundamental of an applied A. C. field. Also it is known that certain dielectric materials of the ceramic type have rather large dielectric constants. Such materials would have some very desirable characteristics for use as the operating element of electromechanical transducers were it not for the fact that they normally do not have the desirable linear response

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characteristic mentioned above. One such ceramic material is a composition containing a substantial portion of barium titanate in its composition. I have discovered that it is possible to polarize this material to provide the desirable type of response mentioned above. I have also discovered that very surprisingly large ratios of strain to applied voltage are possible with this material. Inasmuch as ceramic materials containing a substantial portion of barium titanate exhibit extreme stability with reference to temperature and chemical influences, very great advantages are obtained in an electromechanical transducer using such ceramic materials.

As used in this specification, the phrase "polarized to respond to the fundamental component of an alternating electrical field applied thereto in at least one mechanical mode" means any operation upon the material which will enable it to respond as a first order effect to the fundamental of an applied A. C. field which response, as indicated above, is not the usual response of materials of this type. The word "mode" as used herein is intended to designate a direction of expansion and contraction in the material. Furthermore, it is to be noted that the quoted language does not state that an alternating field is actually applied to the material. This is important because in some cases no such alternating electrical field is applied but rather mechanical vibrations are applied to the material in order to derive from the material electric energy corresponding to the mechanical vibrations.

It is an object of the invention to provide an improved electromechanical transducer of the type in which mechanical action results from the application of an electrostatic field and vice versa.

It is a further object of the invention to provide an improved electromechanical transducer which may be readily and inexpensively produced and which is rugged and relatively immune to the influence of ambient conditions, such as temperature and humidity effects.

It is a further object of the invention to provide an improved electromechanical transducer by using as the operating element thereof, a material having a substantial portion of barium titanate in its composition.

In accordance with the invention, an electromechanical device for transducing between the types of energy which are classified as electrical and mechanical comprises a dielectric material polarized primarily to respond to the fundamental component of an alternating field applied

thereto in at least one mechanical mode. Means are also provided for applying energy of one of the above-mentioned types to the material together with means dependent upon the effect of the applied energy upon the material for deriving and utilizing energy of the other of said above-mentioned types.

For a better understanding of the present invention together with other and further objects thereof, reference is had to the following description taken in connection with the accompanying drawing, and its scope will be pointed out in the appended claims.

In the single sheet of the drawing, Figure 1 is provided to illustrate the mode of operation of the transducer of the invention; Figure 2 illustrates a transducer utilizing the actuating element of Fig. 1 as a generator of ultrasonic vibrations; Figs. 3 and 4, respectively, are a sectional view and a plan view partly broken away of a microphone embodying the transducer of the invention together with suitable circuit connections to an amplifier stage; and Fig. 5 is a sectional view of an earphone embodying the transducer element of the invention together with suitable circuit connections from the output stage of an amplifier.

Referring now more particularly to Fig. 1, there is illustrated a simple form of actuating element for an electromechanical transducer which includes a dielectric material as the actuating element thereof. While any dielectric material may be used as the operating element of the arrangements of the invention, it is preferable to use a material having a high dielectric constant in order to provide a high coupling between the electrical and mechanical action of the operating element. Also it has been discovered that the class of materials known as "titanates" is particularly useful in the arrangements of the invention. Particularly has it been discovered that materials having a substantial portion of barium titanate in their composition are very useful in most embodiments of the invention. The actuating element of Fig. 1 comprises a thin disk-shaped body 10, provided with electrodes 11 and 12 on the major faces of the disk. For the reasons given above, the body 10 preferably contains a substantial portion of barium titanate in its composition. Lead wires 13 and 14 are connected to the electrodes by any suitable means, such as soldering, conductive cement, or pressure springs. The actuating element is connected in a circuit comprising a generator 9, a battery 15, and a switch 16. The voltage of source 15 must be high in relation to that of the generator 9.

In considering the action of the arrangement of Fig. 1 and neglecting for the moment the presence of generator 9, it will be seen that upon closure of the switch 16 the condenser formed by electrodes 11 and 12, separated by the dielectric material 10, is charged. In the work leading to the making of this invention it was found that there is a strong tendency for the material 10 to contract radially as illustrated by the arrows 17-17 and simultaneously to expand in the thickness direction as illustrated by the arrows 19-19. It was determined experimentally that for a particular material including a substantial portion of barium titanate, the strain in a direction parallel to the electrodes is about $0.55 \cdot 10^{-4}$ and that the strain in the direction perpendicular to the electrodes is about $4.5 \cdot 10^{-4}$ for a voltage gradient of 1 kilovolt/mm. The effect

of the generator 9 is explained more fully in connection with the generator of Figure 2.

The nature of the mechanical action of the transducer of Figure 1 makes it very suitable for the generation or reception of ultrasonic vibrations in liquids. In Fig. 2 there is illustrated one simple arrangement for utilizing the transducer of the invention for this purpose. Components in Fig. 2 which correspond to those of Fig. 1 have identical reference numerals. In Fig. 2, the transducer is suspended in a beaker 21 by its leads 13, 14 which are secured to an insulating bar 22 resting on the top of the beaker. The leads 13, 14 are connected to a source of high frequency alternating current 23, through a source of polarizing potential 24. Preferably a variable inductor 25 is shunted across the source 23. The beaker contains a liquid 26 which may, for example, be an oil containing dissolved gases.

In considering the operation of the arrangement of Fig. 2, it will first be stated that the material 10 is polarized by the source 24, as defined above, to respond to the fundamental of an applied alternating field. The transducer is thus driven by the generator 23, preferably, but not necessarily, at a mechanical resonance frequency of the transducer. Under these conditions strong ultrasonic vibrations are set up in the liquid and the dissolved gases are gradually driven off. The dielectric constant of most materials containing a substantial portion of barium titanate is quite high and, as a result, the operating element of Fig. 2 tends to draw from the generator 23 a large reactive component of current which is not useful directly in generating the ultrasonic vibrations used to drive off the gases of the liquid. For best operation, therefore, the inductor 25 and the capacitance of the transducer including the element 10 should be adjusted to be in resonance, or approximately in resonance, at the frequency of operation of generator 23. If the generator 23 has a low internal impedance, it may be desirable to connect the inductor 25 in series with the generator 23 rather than in parallel as shown.

In Figs. 3 and 4 there is illustrated a microphone of simple construction embodying an electromechanical device in accordance with the invention. This arrangement comprises a cup-shaped housing 30 to the bottom of which is secured a bar-shaped body 31 which is comprised of a material having a high dielectric constant and preferably of a material having a substantial portion of barium titanate therein. The body 31 is provided with electrodes 32 and 33 on its major faces. One convenient way of securing the transducer actuating element to the housing is to connect it to thin pads of rubber or like material 34, 35 and to cement the pads to the housing. To the upper surface of the actuating bar 32 is cemented a toggle-type lever element 26 formed of a thin sheet of aluminum or other like material. The apex of this lever element is connected by means of a pin 37 to the apex of a cone-shaped metal diaphragm 38. The diaphragm 38 is secured around its periphery to the housing 30, for example by cementing, and the pin 37 is secured to the diaphragm and toggle lever 36 by any suitable means, such as cement or wax. The electrodes 32 and 33 are connected by lead wires to terminals 40, 41 which serve to connect the microphone to an amplifier. A suitable amplifier is illustrated in the drawings. It comprises a vacuum tube 42 which may be a triode or pentode, preferably having a relatively

high mutual conductance, and connected as a cathode follower. Thus the tube 42 is provided with a cathode resistor 43, one end of which is grounded, and the output signals are derived from terminals 44, 45 connected across the resistor 43. The tube 42 is also provided with a grid resistor 39 connected between the grid of tube 42 and a tapping point on resistor 43. Operating potentials are provided for the tube 42 by a source indicated +B.

In considering the operation of the microphone of Figures 3 and 4, it will be sufficient to say that its operation is quite analogous to the operation of the more conventional transducer units employing sections cut from single crystals, such as Rochelle salt or ammonium dihydrogen phosphate. Sound waves impinging on diaphragm 38 apply, through pin 37, vibratory forces to the apex of the toggle lever 36 and these forces are transmitted by the lever and applied to the bar 31 as vibratory expansion and compression forces. As a result of these forces, corresponding alternating potentials are developed between the electrodes 32 and 33. These alternating potentials corresponding to the sound wave are conducted to the input terminals of the amplifier. It is to be noted here that the unidirectional voltage which exists across the grid leak resistor 39 and the portion of resistor 43 between the tapping point and ground, due to the application of potentials from the source +B, is applied across the electrodes 32, 33. The bar of material 31, therefore, becomes polarized in accordance with the definition given above and thereafter behaves in a manner analogous to a piezoelectric element developing alternating potentials in response to alternating forces.

The theory of operation of cathode follower circuits is too well known to require detailed description. It is sufficient to state that the alternating voltage developed between electrodes 32 and 33 is called upon to supply almost negligible current because of the high input impedance of the cathode follower. The output circuit of the cathode follower, however, is capable of supplying a substantial amount of signal current at a voltage slightly less than the input signal. Thus it is quite useful as a preamplifier between the high impedance transducer element and a cable or other line running to a succeeding amplifier circuit.

For a further discussion of the operation and characteristics of cathode follower circuits in connection with piezoelectric and other electrostatic transducers, reference may be had to U. S. Letters Patent 2,288,600 granted on July 7, 1942, to J. P. Arndt, Jr., and assigned to the same assignee as the present invention. It should be noted, however, that in the case of the present invention, it is not necessary to take precautions against application of direct voltages to the actuating element of the transducer as outlined in the patent.

Fig. 5 illustrates an earphone using the same type of element and construction as is used in the microphone of Figs. 3 and 4, and corresponding elements in the several figures have identical reference numerals. In Fig. 5, however, the diaphragm 38 is covered by an ear-cap 50 which tends to concentrate the sound pressure developed by the vibrating diaphragm. In this arrangement the alternating signals which are to be converted to sound pressure vibrations are applied to the input circuit of a vacuum tube 51 through input terminals 52 and 53 and the

amplified potentials appearing across the load resistor 54 are applied through a flexible cord 56 to the electrodes 32, 33 of the operating material 31.

In considering the operation of the arrangement of Fig. 5, it will be seen that when the tube 51 is energized, the potential +B automatically polarizes the material 31 and therefore it functions in a manner somewhat analogous to a piezoelectric element as explained above. The material 31 thus expands and contracts in response to the alternating component of the anode potential of tube 51. This alternating expansion and contraction is amplified by the toggle lever 36 to impart a much larger vibratory motion to the diaphragm 38 and, when the device is placed against the user's ear, corresponding sound pressure vibrations are developed in the ear canal.

Each of the arrangements described above may be seen to comprise an electromechanical device for transducing between the types of energy which are classified as electrical and mechanical. Specifically, some of the embodiments of the invention, for example Fig. 3, are adapted to transduce mechanical energy to electrical energy. The embodiment of the invention illustrated in Fig. 5 on the other hand is adapted to transduce electrical energy derived from the output circuit of vacuum tube 51 into mechanical energy which in turn produces sound to be heard by the human ear. In each embodiment of the invention which has been described the actuating material includes a dielectric material polarized primarily to respond to the fundamental component of an alternating field applied thereto in at least one mechanical mode or direction. In each of the embodiments of the invention which has been described the actuating material is polarized by the application thereto of a unidirectional field, although it is to be distinctly understood that I do not wish to limit my invention to polarization in this particular manner.

While any material which contains a substantial portion of barium titanate is useful as the operating element of the invention, materials having at least fifty per cent of barium titanate have been found to give the best results. Such materials usually have a dielectric constant of at least 1,000 and, in fact, it may be stated that, in general, it is preferable to use a material in the actuating element which has a dielectric constant as high as possible. Certain materials containing a substantial portion of barium titanate are available commercially through such firms as The Titanium Alloy Manufacturing Company of Niagara Falls, New York.

In British Patent 583,639, based on an application filed November 10, 1944, of The Titanium Alloy Manufacturing Company of 111 Broadway, New York city, there are disclosed tables relating to various compositions which contain a substantial portion of barium titanate. As stated above, any of these materials which have a dielectric constant around 1,000 or more are suitable for the purposes of the present invention.

In my copending application Serial Number 740,461, now U. S. Patent Number 2,484,950, dated October 18, 1949, filed concurrently with the instant application, there are described and claimed arrangements utilizing the principles of the present invention as applied to multiple-element operating elements to provide actuators for electromechanical transducers of the "bender" type.

While the invention has been described with a

certain degree of particularity, it is to be understood that it has been by way of example and that changes can be made without departing from the spirit and scope of the invention.

I claim as my invention:

1. An electromechanical device for transducing between the types of energy which are classified as electrical and mechanical comprising, a body of polycrystalline dielectric material having conductive electrodes on two faces thereof, means for maintaining a unidirectional potential between said electrodes to polarize said material, said polarized material having a substantial response to the fundamental component of an alternating electrical field applied thereto in at least one mechanical mode, means for applying energy of one of said types to said material, and means dependent upon the effect of said applied energy upon said material for deriving and utilizing energy of said other type.

2. An electromechanical device for transducing between the types of energy which are classified as electrical and mechanical comprising, a body of polycrystalline dielectric material having a substantial portion of barium titanate therein and having conductive electrodes on two faces thereof, means for maintaining a unidirectional potential between said electrodes to polarize said material, said polarized material having a substantial response to the fundamental component of an alternating electrical field applied thereto in at least one mechanical mode, means for applying energy of one of said types to said material, and means dependent upon the effect of said applied energy upon said material for deriving and utilizing energy of said other type.

3. An electromechanical device for transducing between the types of energy which are classified as electrical and mechanical comprising, a layer of polycrystalline dielectric material having individual conductive electrodes on the two major faces thereof, means for maintaining a unidirectional potential between said electrodes to polarize said material, said polarized material having a substantial response mechanically, to the fundamental component of an alternating electrical field applied thereto, in at least its thickness direction, means for applying energy of one of said types to said material, and means dependent upon the effect of said applied energy upon said material for deriving and utilizing energy of said other type.

4. An electromechanical device for transducing between the types of energy which are classified as electrical and mechanical comprising, a layer of polycrystalline dielectric material having individual conductive electrodes on the two major faces thereof, means for maintaining a unidirectional potential between said electrodes to polarize said material, said polarized material having a substantial response to the fundamental component of an alternating electrical field applied thereto in a mechanical mode corresponding to its dimension of greatest length, means for applying energy of one of said types to said material, and means dependent upon the effect of said applied energy upon said material for deriving and utilizing energy of said other type.

5. An electromechanical device for transducing electrical energy to mechanical energy comprising, a body of polycrystalline dielectric material having conductive electrodes on two faces thereof, means for maintaining a unidirectional potential between said electrodes to polarize said material, said polarized material having a sub-

stantial response to the fundamental component of an alternating electrical field applied thereto in at least one mechanical mode, means including said electrodes for applying electrical energy to said material, and means dependent upon the effect of said applied electrical energy upon said material for deriving and utilizing mechanical energy.

6. An electromechanical device for transducing mechanical energy to electrical energy comprising, a body of polycrystalline dielectric material having conductive electrodes on two faces thereof, means for maintaining a unidirectional potential between said electrodes to polarize said material, said polarized material having a substantial response to the fundamental component of an alternating electrical field applied thereto in at least one mechanical mode, means for applying mechanical energy to said material, and means including said electrodes, dependent upon the effect of said applied mechanical energy upon said material for deriving therefrom and utilizing electrical energy.

7. A device for transducing between electrical and mechanical energy comprising: a solid body of polycrystalline dielectric material polarized by the application of a unidirectional electrical potential, said polarized material having a substantial response to the fundamental component of an alternating electrical field applied thereto, in at least one mechanical mode; means including electrodes adjacent to two surfaces of said body for translating currents associated with electrostatic energy transduced in said body; and means for supporting said body in vibration-translating relationship to a medium capable of transmitting hydrostatic pressure.

8. A device for transducing between electrical and mechanical energy comprising: a solid body of polycrystalline barium titanate dielectric material polarized by the application of a unidirectional electrical potential, said polarized material having a substantial response to the fundamental component of an alternating electrical field applied thereto, in at least one mechanical mode; means including electrodes adjacent to two surfaces of said body for translating currents associated with electrostatic energy transduced in said body; and means for supporting said body substantially unconstrained in a medium capable of transmitting hydrostatic pressure.

9. A device for transducing between electrical and mechanical energy comprising: a solid body of polycrystalline dielectric material; means including electrodes adjacent to two surfaces of said body for translating currents associated with electrostatic energy transduced in said body; means for maintaining a unidirectional potential between said electrodes to polarize said material, said polarized material having a substantial response in at least one mechanical mode to the fundamental component of an alternating electrical field applied thereto; and means for supporting said body in a liquid medium for translating vibratory energy between said body and said medium.

10. An electromechanical device for transducing electrical energy to mechanical energy comprising: a body of polycrystalline dielectric material having individual conductive electrodes on separate faces thereof; means for maintaining a relatively high unidirectional voltage across said electrodes to condition said material, said conditioned material having a substantial re-

sponse in at least one mechanical mode to any relatively low alternating voltage applied to said electrodes; means including said electrodes for applying electrical energy to said material; and means dependent upon said substantial mechanical response of said material to said applied electrical energy for deriving and utilizing mechanical energy.

HANS JAFFE.

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