Jan. 22, 1957 D. H. FRYKLUND 2,778,881

MICROPHONE

Filed Aug. 3, 1951

Fig. 1.

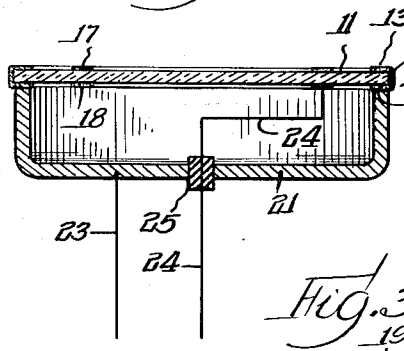


Fig. 2.

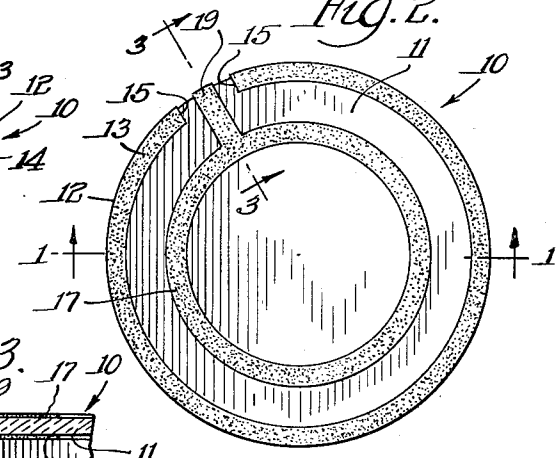


Fig. 3.

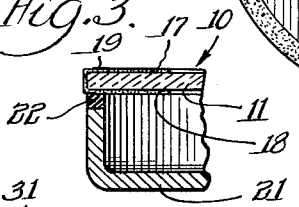


Fig. 4.

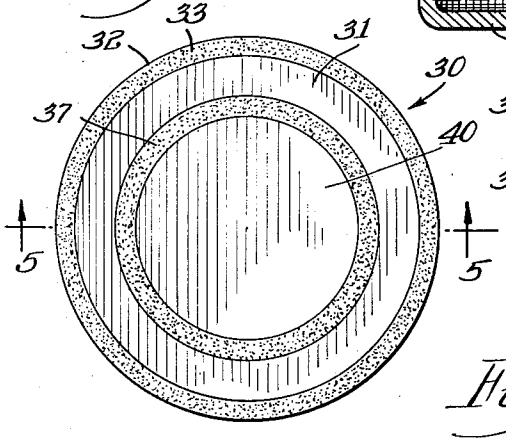


Fig. 5.

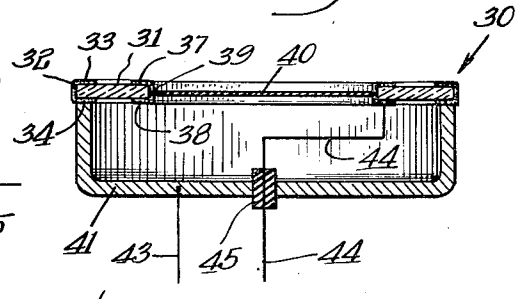


Fig. 6.

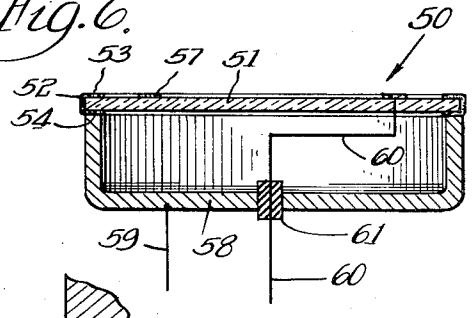
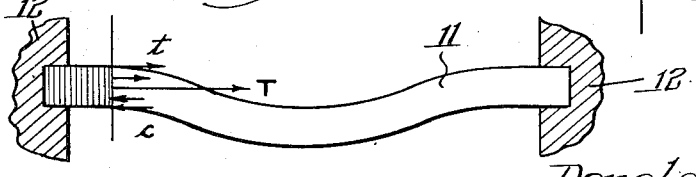


Fig. 7.



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2,778,881

MICROPHONE

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14 Claims. (Cl. 179—110)

This invention relates to microphones and more particularly to microphones utilizing piezoelectric materials for producing voltages in accordance with wave energy.

A circular membrane or diaphragm that is clamped at its edge has a mechanical impedance variation with distance along its diameter, the mechanical impedance being considerably less at its center than at its edge. Conventional practice in the construction of crystal microphones is to couple a piezoelectric crystal pickup element of low mechanical impedance by means of a push rod onto the center of a membrane which in turn acts as a diaphragm to match into the air and be flexed by wave energy. However, considerable mechanical mismatch results due to the fact that the pickup element cannot be designed to have a mechanical impedance as low as the center of the diaphragm and a loss in sensitivity results.

When it is attempted to reduce the mechanical impedance of the piezoelectric crystal pickup element more nearly to match that of the membrane or diaphragm, then the internal electrical capacity, or the sensitivity, thereof is decreased, requiring the use of costly special amplifier circuits, low capacity cables, and the like. Loss in sensitivity results also due to loose coupling caused by the indirect means by which the diaphragm delivers its energy to the piezoelectric element, i. e., through two cemented joints at each end of the push rod. The complex mechanism of the conventional design contributes toward a system that has more than one natural frequency of oscillation. These parasitic oscillation systems can cause a non-uniform frequency response of the microphone.

The principal object of this invention is to provide an improved microphone of the piezoelectric type wherein the aforementioned faults of conventional microphones of this type are eliminated, wherein higher sensitivity is obtained, wherein parasitic systems of oscillation are eliminated and more uniform frequency response is obtained, wherein higher internal electrical capacities are obtained, wherein the construction is materially simplified, and wherein closer mechanical coupling and mechanical impedance matching are obtained.

As expressed above, higher mechanical impedance is realized at the edge of a membrane or diaphragm than at its center, so that, in accordance with this invention, if a piezoelectric pickup element of proper shape is placed in that region, a mechanical impedance match between the membrane or diaphragm and the pickup element will result. By placing the piezoelectric pickup element around the edge of the membrane or diaphragm, instead of at the center, closer coupling of the mechanical forces into the electrical system is realized. In accordance with this invention, the pickup element includes a titanate ceramic, such as barium titanate, strontium titanate, and the like, which may be formed into the desired shape and which may be polarized to make the same piezoelectric for accomplishing the purposes of this invention.

Briefly, the microphone of this invention includes a titanate ceramic disc adapted to be flexed by wave energy and supporting means secured to the edge of the disc for supporting the same. As wave energy, such as sound waves, acts upon the disc it is mechanically flexed and vibrated in accordance with the strength and frequency of such wave energy just as in the case of a conventional membrane or diaphragm. A first annular electrode is provided on the disc adjacent the outer edge thereof and a second annular electrode is also provided on the disc but spaced inwardly from the first annular electrode. The disc is polarized between the first and second annular electrodes to make the same piezoelectric. Electrical connections to the respective electrodes produce an electrical voltage in accordance with the mechanical flexing of the disc by the wave energy. Thus, with the microphone of this invention closer mechanical coupling, better mechanical impedance match, higher sensitivity, more uniform frequency response, simpler mechanical construction, and higher internal electrical capacity are afforded.

In one form of this invention the titanate ceramic disc may be a solid disc and in another form it may be provided with a central hole in which is marginally received a diaphragm of metallic foil. Both arrangements utilize the same principles and objects of this invention, namely, the location of the piezoelectric pickup at the outer edge of the disc to obtain the new, useful, and unexpected results. The frequency response of the microphones is controlled by proper selection of the diameter and/or the thickness of the ceramic disc. By utilizing the form of the invention having a diaphragm of metallic foil, the frequency range may be extended beyond that of the solid ceramic disc form.

The two annular electrodes on the ceramic disc may take the form of two pairs of electrodes, each pair of electrodes having an electrode on each face of the disc with the electrodes of each pair electrically connected together. By changing the distance between the two pairs of electrodes, the open circuit output voltage per unit sound pressure, henceforth simply called open circuit output voltage, may be varied. However, the internal capacitance varies inversely with the open circuit voltage and, hence, the minimum capacitance that can be used with a particular amplifier circuit for a given frequency response determines the highest open circuit output voltage than can be realized with the microphone. The two annular electrodes may be placed on only one side, such as the top side, of the ceramic disc to obtain slightly more output voltage, but here again this reduces the internal capacitance. By utilizing the two pairs of electrodes rather than electrodes on one side only of the ceramic disc, an increase in capacitance of 100% is gained at the expense of a decrease in open circuit output voltage of less than 10%.

The support for the ceramic disc may be a metal case which is firmly secured and pressure sealed to the outer edge of the ceramic disc. The metal case may also form the electrical connection to the outer annular electrode. A suitable electrical connection is also provided for the inwardly spaced annular electrode and preferably this electrical connection extends through and is electrically insulated from the metal case.

Further objects of this invention reside in the details of construction of the microphone and in the construction of and cooperative relationships between the component parts thereof.

Other objects and advantages of this invention will become apparent to those skilled in the art upon reference

to the accompanying specification, claims and drawings, in which:

Fig. 1 is a vertical sectional view through one form of the microphone of this invention and taken substantially along the line 1—1 of Fig. 2;

Fig. 2 is a top plan view of the microphone of Fig. 1;

Fig. 3 is a partial sectional view taken substantially along the line 3—3 of Fig. 2;

Fig. 4 is a top plan view of another form of the microphone of this invention;

Fig. 5 is a vertical sectional view taken substantially along the line 5—5 of Fig. 4;

Fig. 6 is a vertical sectional view of still another form of the microphone of this invention; and

Fig. 7 is a diagrammatic view illustrating the principles of operation of this invention.

One form of the microphone of this invention is generally designated at **10** in Figs. 1 to 3. This microphone includes a thin titanate ceramic disc, preferably formed of substantially pure barium titanate, the disc being substantially .005 inch thick. This thin titanate ceramic disc may be made by the methods disclosed in patent No. 2,486,410 and fired to a sufficiently high temperature to set the same and drive off all organic materials which may be present as binders or the like. This titanate ceramic disc **11** is adapted to be flexed by wave energy, such as sound waves, in accordance with the strength and frequency of such wave energy just as in the case of a conventional membrane or diaphragm utilized in microphones. This titanate ceramic disc is also capable of being polarized to make the same piezoelectric.

A first annular electrode **12** is applied to disc **11** adjacent the outer edge thereof. This annular electrode may include a pair of electrodes **13** and **14** which are disposed on opposite faces of the ceramic disc **11** and electrically connected together. These annular electrodes **13** and **14** may comprise silver paste which is applied to the ceramic disc and then fired to a sufficiently high temperature to fuse the same to the disc. As shown in Fig. 2, this annular electrode **12** is not continuous but is separated, as indicated at **15**.

A second annular electrode is also applied to the disc and this second annular electrode is spaced inwardly from the first annular electrode. This second annular electrode also may include a pair of electrodes **17** and **18** with one electrode on each face of the ceramic disc. The electrodes **17** and **18** may be electrically connected together by a tab **19** extending over the edge of the disc between the ends **15** of the outer electrode **12**, as shown more particularly in Figs. 2 and 3. These electrodes **17** and **18** and the tab **19** may also be formed from silver paste which is suitably fused to the ceramic disc **11**. The ceramic disc **11** is secured to and preferably pressure sealed to a support in the form of a metal cup **21**, as by cementing or soldering the electrode **14** thereto. This metal support **21** operates firmly to support the periphery of the ceramic disc **11** to pressure seal the underside of the disc **11** and to establish electrical connection to the outer annular electrode **12**. To prevent electrical conduction between the metal casing **21** and the connecting tab **19** for the inner electrodes **17** and **18**, a suitable insulating member **22** is interposed between the tab **19** and the metal case **21**. A lead **23** is connected to the case **21** and a lead **24** is connected to the annular electrode **18**, the lead **24** extending through the metal case **21** and electrically insulated therefrom by an insulator **25**.

After the microphone is assembled, a polarizing voltage is applied across the leads **23** and **24** for the purpose of permanently polarizing the titanate ceramic disc **11** between the inner and outer annular electrodes to make the same piezoelectric. In so polarizing the ceramic disc **11**, the inner annular electrode **17**, **18** is made positive with respect to the outer annular electrode **12**. The voltage applied for polarization purposes is made sufficiently high and is applied for a sufficiently long period of time in order permanently to polarize the titanate ceramic.

As sound energy acts upon the titanate ceramic disc **11**, the disc is flexed to produce mechanical movement therein which, due to the piezoelectric characteristics of the disc, produces voltages across the leads **23** and **24** in accordance with the strength and frequency of the flexing of the disc.

Another form of the microphone is illustrated in Figs. 4 and 5 and it is essentially the same as that illustrated in Figs. 1 and 2, except that the ceramic disc is provided with a central hole and a diaphragm of metallic foil is marginally secured within the hole. This microphone is generally designated at **30** and includes a titanate ceramic disc **31** having a hole in the center thereof. It also includes an outer annular electrode **32** consisting of a pair of electrodes **33** and **34** electrically connected together and an inner annular electrode consisting of a pair of electrodes **37** and **38** electrically connected together at **39**. This inner annular electrode is formed over the edge of the hole in the titanate ceramic disc **31** in the same way that the outer annular electrode **32** is formed over the outer edge of the titanate ceramic disc **31**. A diaphragm **40** formed from a metallic foil, such as aluminum foil, is marginally secured in the hole in the ceramic disc **31** as by cement or the like. Preferably a pressure-tight seal is made at this point. The titanate ceramic disc **31** and its metallic foil diaphragm **40** are secured and pressure sealed to a metallic supporting case **41**, the case **41** establishing an electrical connection to the outer annular electrode **32**. A lead **43** is connected to the metal case **41** and a lead **44** is connected to the inner annular electrode **38** and extends through the metal case **41** and is insulated therefrom by an electrical insulator **45**.

The ceramic disc **31** is polarized in the manner set forth above so that as wave energy acts upon the diaphragm **40**, a voltage is produced across the leads **43** and **44** corresponding to the strength and frequency of the wave energy. The microphone of Figs. 4 and 5 operates in the same manner as the microphone of Figs. 1 to 3, with the exception that a somewhat extended frequency range may be obtained by the microphone of Figs. 4 and 5.

The microphone generally designated at **50** in Fig. 6 is like the microphone **10** of Figs. 1 to 3, with the exception that it utilizes only a single inner annular electrode rather than a pair of inner annular electrodes. Here, the microphone **50** includes a titanate ceramic disc **51** having an outer annular electrode **52** which includes a pair of electrodes **53** and **54** on opposite faces of the ceramic disc and electrically connected together. A single annular electrode **57** is formed on the one side only of the ceramic disc **51**, preferably the top side. The ceramic disc **51** is supported by a metal supporting case **58** in the same manner as pointed out above. A lead **59** is connected to the metal case **58** and a lead **60** is connected to the electrode **57**, the lead **60** extending through the metal case **58** and insulated therefrom by an insulator **61**. The ceramic disc **51** is polarized between the electrodes **52** and **57** to make the same piezoelectric in the manner pointed out above. Here, also, the manner of operation of the microphone **50** is substantially the same as the manner of operation of the microphones **10** and **30**, with the exception that slightly higher voltages may be obtained.

In all forms of the invention the frequency response of the microphones is controlled by proper selection of diameter and/or thickness of the ceramic disc and, by utilizing the form of the invention illustrated in Figs. 4 and 5, the frequency range may be made somewhat extended beyond that of the forms of the invention utilizing solid ceramic discs as illustrated in Figs. 1 to 3 and 6. By changing the distance between the inner and outer annular electrodes, the open circuit output voltage may

be varied. However, the internal capacitance varies inversely with this voltage and, hence, the minimum capacitance that can be used for a particular amplifier circuit for a given frequency response determines the highest open circuit output voltage that can be realized with the microphone.

Referring now to Fig. 7 which illustrates the principle of this invention, when the ceramic disc **11** is flexed there is a force T which tends to pull the edges of the ceramic disc away from its mounting and forces *t* and *c* which tend to resist bending. The forces T and *t* act together in the direction of bending as shown in Fig. 7, while the forces *t* and *c* are in opposition. When a pair of inner electrodes **17** and **18** are utilized, the effects of the forces *t* and *c* are canceled so that the only effective force is the force T. When, however, a single inner electrode **57** is utilized, the force *c* does not cancel the force *t* so that the effective forces are a summation of T and *t*. Thus, somewhat higher voltages are realized when the single inner annular electrode **57** is used than when the pair of inner annular electrodes **17** and **18** are used. However, the use of the single electrode **57** in lieu of the pair of electrodes **17** and **18** decreases materially the internal capacitance of the microphone. By utilizing the pair of annular electrodes **17** and **18**, the internal capacitance may be increased as much as 100% at the expense of a decrease in output voltage of less than 10%. Thus, if primary importance is placed upon voltage output with only secondary importance placed on internal capacitance, then it probably would be advisable to utilize the form of microphone **50** having the single inner electrode **57**. If, however, internal capacitance is of primary importance, then the microphone **10** utilizing the pair of internal electrodes should be utilized.

In all forms of this invention, close mechanical coupling and close mechanical impedance matching is obtained between the center portion of the disc and the outer portion thereof. As a result, high sensitivity and uniform frequency response are obtained due to the elimination of parasitic systems of oscillation. By reason of this invention it is also possible to obtain relatively hgh internal electrical capacitance without sacrificing sensitivity and frequency response. The constructions of the microphones of this invention are extremely simple and make them capable of foolproof operation over long periods of time.

While for purposes of illustration several forms of this invention have been disclosed, other forms thereof may become apparent to those skilled in the art upon reference to this disclosure. Therefore, this invention is to be limited only by the scope of the appended claims.

I claim as my invention:

1. A microphone comprising a titanate ceramic disc, supporting means secured to the edge of the disc for stationarily supporting the disc, said disc being mechanically flexed by wave energy in the direction of its central axis, a first annular electrode on the disc adjacent the edge thereof, a second annular electrode on the disc spaced inwardly from the first annular electrode, said disc being polarized between the first and second annular electrodes to make the same piezoelectric, and electrical connections to the respective electrodes for producing an electrical voltage in accordance with mechanical flexing of the disc.

2. A microphone comprising a titanate ceramic disc, supporting means secured to the edge of the disc for stationarily supporting the disc, said disc being mechanically flexed by wave energy in the direction of its central axis, a first pair of annular electrodes on the disc adjacent the edge thereof with one electrode on each face of the disc and electrically connected together, a second pair of annular electrodes on the disc spaced inwardly from the first pair of annular electrodes and with one electrode on each face of the disc and electrically connected together, said disc being polarized between the first and second pairs of annular electrodes to make the same piezoelectric, and electrical connections to the respective pairs of electrodes for producing an electrical voltage in accordance with mechanical flexing of the disc.

3. A microphone comprising a titanate ceramic disc, supporting means secured to the edge of the disc for stationarily supporting the disc, said disc being mechanically flexed by wave energy in the direction of its central axis, a first annular electrode on one side of the disc adjacent the edge thereof, a second annular electrode on the same side only of the disc and spaced inwardly from the first annular electrode, said disc being polarized between the first and second annular electrodes to make the same piezoelectric, and electrical connections to the respective electrodes for producing an electrical voltage in accordance with mechanical flexing of the disc.

4. A microphone comprising a titanate ceramic disc having a hole in its center, a diaphragm of metallic foil marginally secured in the central hole of the disc, the diaphragm and disc being mechanically flexed by wave energy in the direction of their central axes, a first annular electrode on the disc adjacent the edge thereof, a second annular electrode on the disc spaced inwardly from the first annular electrode, said disc being polarized between the first and second annular electrodes to make the same piezoelectric, and electrical connections to the respective electrodes for producing an electrical voltage in accordance with mechanical flexing of the diaphragm and disc.

5. A microphone comprising a titanate ceramic disc having a hole in its center, a diaphragm of metallic foil marginally secured in the central hole of the disc, the diaphragm and disc being mechanically flexed by wave energy in the direction of their central axes, a first pair of annular electrodes on the disc adjacent the edge thereof with one electrode on each face of the disc and electrically connected together, a second pair of annular electrodes on the disc spaced inwardly from the first pair of annular electrodes and with one electrode on each face of the disc and electrically connected together, said disc being polarized between the first and second pairs of annular electrodes to make the same piezoelectric, and electrical connections to the respective pairs of electrodes for producing an electrical voltage in accordance with mechanical flexing of the diaphragm and disc.

6. A microphone comprising a titanate ceramic disc, a metal case secured and pressure sealed to the edge of the disc for stationarily supporting the disc and enclosing one face of the disc, said disc being mechanically flexed by wave energy in the direction of its central axis, a first annular electrode on the disc adjacent the edge thereof, a second annular electrode on the disc spaced inwardly from the first annular electrode, said disc being polarized between the first and second annular electrodes to make the same piezoelectric, and electrical connections to the respective electrodes for producing an electrical voltage in accordance with mechanical flexing of the disc.

7. A microphone comprising a titanate ceramic disc, a first annular electrode on the edge of the disc and overlying one face of the disc, extending over the edge of the disc and overlying the other face of the disc, a metal case secured and pressure sealed to the first annular electrode for stationarily supporting the disc and enclosing one face of the disc and forming an electrical connection to the first annular electrode, said disc being mechanically flexed by wave energy in the direction of its central axis, a second annular electrode on the disc spaced inwardly from the first annular electrode, the disc being polarized between the first and second annular electrodes to make the same piezoelectric, and an electrical connection to the second electrode extending through the metal case and electrically insulated therefrom for producing an electrical voltage between it and the metallic case in accordance with mechanical flexing of the disc.

8. A microphone comprising a titanate ceramic disc, a

first annular electrode on the edge of the disc and overlying one face of the disc, extending over the edge of the disc and overlying the other face of the disc, a metal case secured and pressure sealed to the first annular electrode for stationarily supporting the disc and enclosing one face of the disc and forming an electrical connection to the first annular electrode, said disc being mechanically flexed by wave energy in the direction of its central axis, a pair of annular electrodes on the disc spaced inwardly from the first annular electrode and with one electrode on each face of the disc and electrically connected together, said disc being polarized between the first annular electrode and the pair of annular electrodes to make the same piezoelectric, and an electrical connection to said pair of electrodes and extending through the metal case and electrically insulating therefrom for producing an electrical voltage between it and the metal case in accordance with mechanical flexing of the disc.

9. A microphone comprising a titanate ceramic disc having a hole in its center, a first annular electrode on the outer edge of the disc, a second annular electrode spaced inwardly from the first annular electrode on the edge of the hole in the disc, a diaphragm of metallic foil secured and pressure sealed to the second annular electrode and closing the hole in the disc, the diaphragm and disc being mechanically flexed by wave energy in the direction of their central axes, a metal case secured and pressure sealed to the first annular electrode for stationarily supporting the disc and diaphragm and enclosing one face of the disc and diaphragm and forming an electrical connection to the first annular electrode, said disc being polarized between the first and second annular electrodes to make the same piezoelectric, and an electrical connection to the second annular electrode and extending through the metal case and electrically insulated therefrom for producing an electrical voltage between it and the metal case in accordance with mechanical flexing of the diaphragm and disc.

10. A wave energy responsive transducer element for a microphone comprising a titanate ceramic disc adapted to be mechanically flexed by wave energy in the direction of its central axis, a first annular electrode on the disc adjacent the edge thereto, and a second annular electrode on the disc spaced inwardly from the first annular electrode, said disc being polarized between the first and second electrodes to make the same piezoelectric.

11. A wave energy responsive transducer element for a microphone comprising a titanate ceramic disc having a hole in its center, a diaphragm of metallic foil marginally secured in the central hole of the disc, the diaphragm and disc being adapted to be mechanically flexed by wave energy in the direction of their central axis, a first annular electrode on the disc adjacent the edge thereof, and a second annular electrode on the disc spaced inwardly from the first annular electrode, said disc being polarized between the first and second electrodes to make the same piezoelectric.

12. A wave energy responsive transducer element for a microphone comprising a titanate ceramic disc adapted to be mechanically flexed by wave energy in the direction of its central axis, a first pair of annular electrodes on the disc adjacent the edge thereof with one electrode on each face of the disc and electrically connected together, and a second pair of annular electrodes on the disc spaced inwardly from the first pair of electrodes with one electrode on each face of the disc and electrically connected together, said disc being polarized between the first and second pairs of electrodes to make the same piezoelectric.

13. A wave energy responsive transducer element for a microphone comprising a titanate ceramic disc adapted to be mechanically flexed by wave energy in the direction of its central axis, a first annular electrode on the disc adjacent the edge thereof, and a second annular electrode on one side only of the disc and spaced inwardly from the first annular electrode, said disc being polarized between the first and second electrodes to make the same piezoelectric.

14. A wave energy responsive transducer element for a microphone comprising a titanate ceramic disc having a hole in its center, a first pair of annular electrodes on the disc adjacent the outer edge thereof with one electrode on each face of the disc and electrically connected together, a second pair of electrodes on the disc adjacent the edge of the hole in the disc with one electrode on each face of the disc and electrically connected together, said disc being polarized between the first and second pairs of electrodes to make the same piezoelectric, and a diaphragm of metallic foil marginally secured in the central hole in the disc, the diaphragm and disc being adapted to be mechanically flexed by wave energy in the direction of their central axes.

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