United States Patent

[11] **3,621,154**

[72] Inventor **James H. Kogen**
Evanston, Ill.
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[73] Assignee **Shure Brothers Inc.**

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[54] **STRAIN-SENSITIVE SEMICONDUCTIVE THIN FILM ELECTROACOUSTICAL TRANSDUCER**
7 Claims, 14 Drawing Figs.

[52] **U.S. Cl.** .... **179/110 B,** 317/235 M
[51] **Int. Cl.** **H04r 23/00**
[50] **Field of Search** .... 179/110.1, 110.2; 310/8.5; 73/88.5 SD; 338/4; 317/235 (26)

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Primary Examiner—Kathleen H. Claffy
Assistant Examiner—Thomas L. Kundert
Attorney—Molinare, Allegretti, Nevitt & Wilcoff

ABSTRACT: A transducer for converting low-level pressure variations (such as sound waves) into electrical signal variations. A strain-sensitive coating is applied to selected surface regions on a flexible diaphragm substrate. A conductive coating is also applied to the substrate flanking the strain-sensitive coating to provide electrical connections for the transducer. Sensitivity of the transducer is enhanced by placing the strain-sensitive coating at points of maximum bending on the diaphragm. The transducer may also include an integrally formed "transistor" to provide an active source of signal gain.

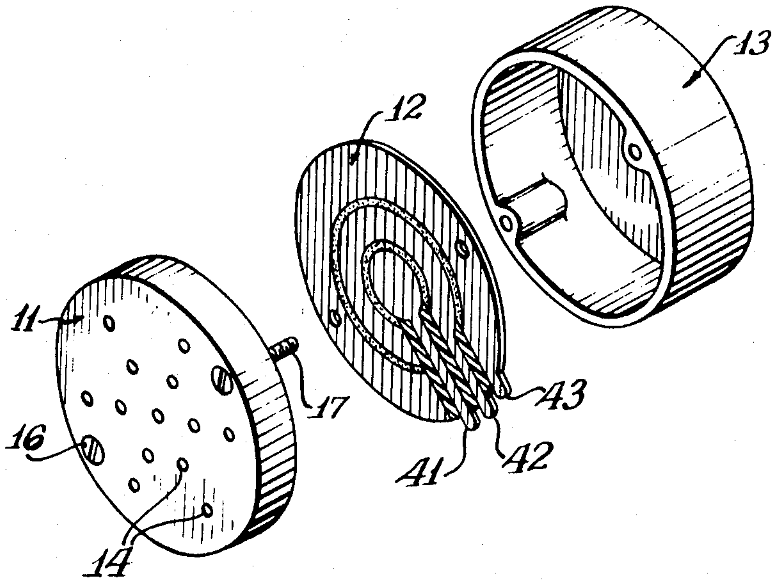


FIG. 1.

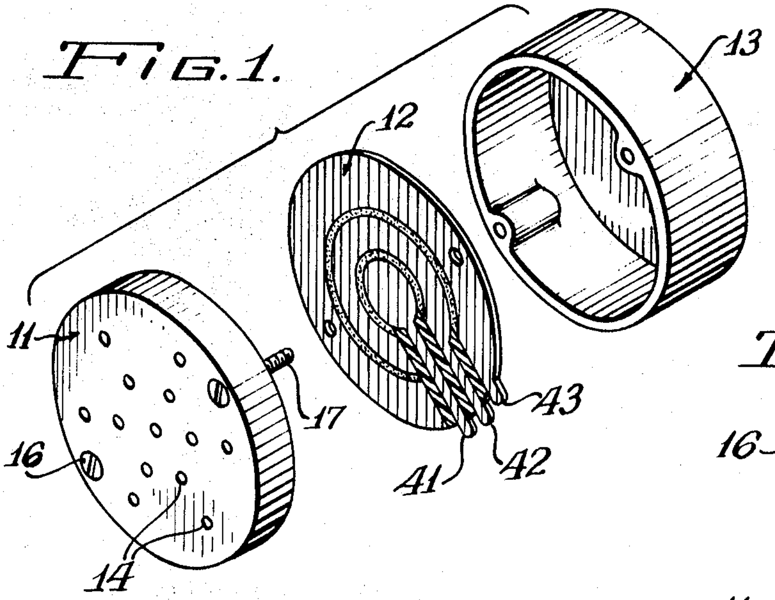


FIG. 2.

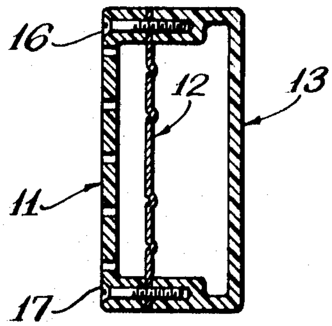


FIG. 3.

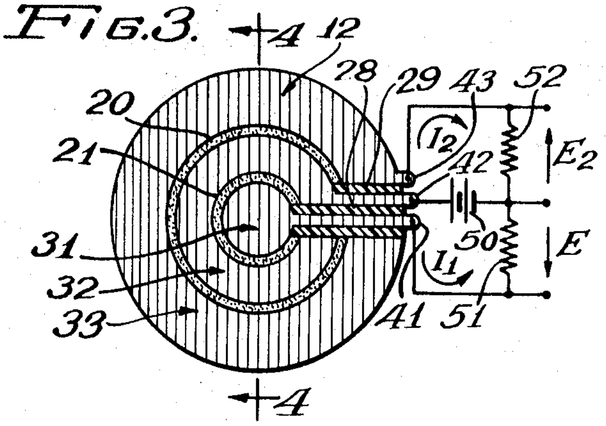


FIG. 4.

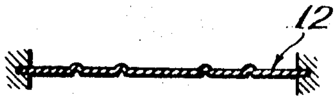


FIG. 5.

FIG. 4A.

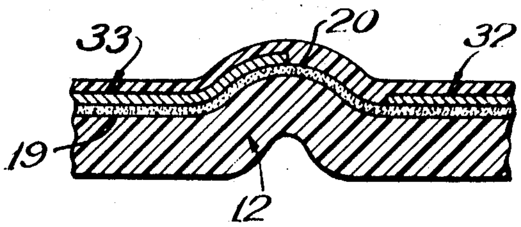
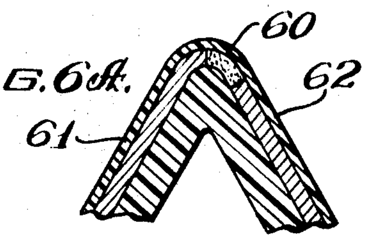


FIG. 6.

FIG. 6A.



Inventor:
James H. Kogen
By Bair, Freeman &
Molinare Attys.

Fig. 7.

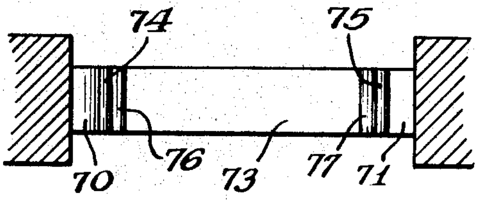


Fig. 8.

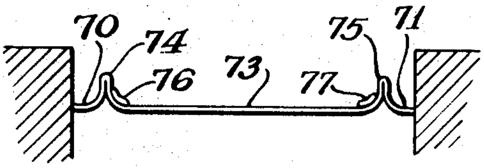


Fig. 9.

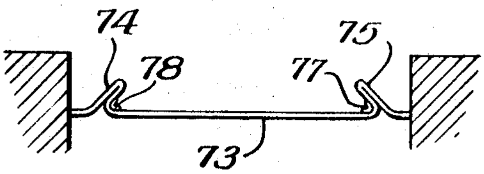


Fig. 8A.

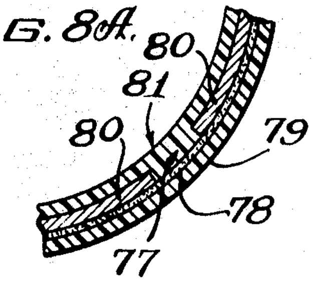


Fig. 10.

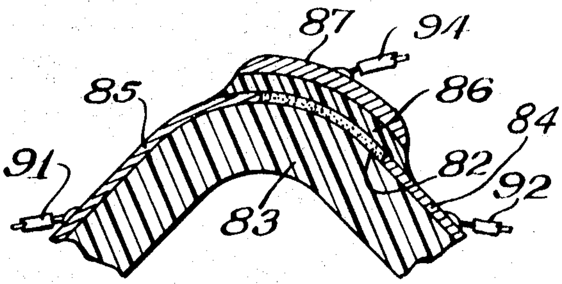
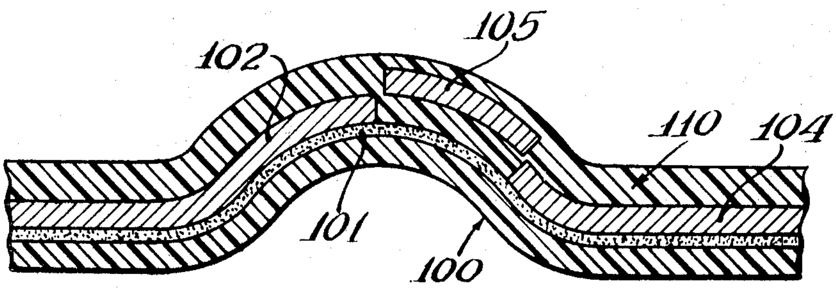


Fig. 11.



Inventor:
James H. Kogen
By Bair, Freeman & Molinare
Attys.

STRAIN-SENSITIVE SEMICONDUCTIVE THIN FILM ELECTROACOUSTICAL TRANSDUCER

BACKGROUND OF THE INVENTION

This invention relates to transducer arrangements for transforming low-level pressure changes into electrical signal variation.

In conventional microphones, a diaphragm is employed in conjunction with a transducer unit to convert acoustical pressure variations into electrical signal variations. In the so-called "carbon" microphone, the sound waves deflect the diaphragm to supply pressure to carbon granules loaded within a chamber, thereby varying the resistance of an electrical path through the granules. In the crystal microphone, the motion of the diaphragm produces mechanical distortion in a crystal with consequent voltage variations being produced across the crystal due to the piezoelectric effect. In the dynamic microphone, the diaphragm is coupled to a coil which is caused to move with respect to a stationary magnetic field, thus creating voltage variations in the coil.

While advances in the state of the art have improved the quality of these basic microphone forms such that improvements in both sensitivity and fidelity have been realized, the use of separate but cooperating diaphragms and transducers has created a certain degree of unavoidable cost and complexity. Moreover, difficulties have been experienced in obtaining the frequency characteristics desired.

SUMMARY OF THE INVENTION

It is accordingly a general object of the present invention to simply and inexpensively produce a transducer responsive to acoustical waves and pressure variations and having versatile performance characteristics adaptable for a wide range of uses.

It is a further object of the invention to transform pressure changes into electrical signal variations with the minimum of cost and complexity.

It is a still further object of the invention to simply and inexpensively produce an exceedingly compact yet highly durable microphone.

In a principal aspect, the present invention takes the form of a novel electroacoustical transducer which consists of a diaphragm upon which is deposited a thin coating of strain-sensitive material. The diaphragm is mounted for bending motion in response to the impingement of acoustical or low-level pressure waves. The consequent bending motion alters the electrical properties of the strain-sensitive coating. Means electrically coupled to the strain-sensitive coating are employed for detecting the amplitude vibratory motion of the diaphragm and translating this motion into the desired fluctuating electrical signal.

In preferred embodiments of the invention, an extremely thin film of strain-sensitive material is applied only to selected portions of the diaphragm, those portions normally being the regions of the diaphragm which undergo maximum bending. The strain-sensitive coating may take the form of a thin film of cadmium sulfide or the like which is vacuum deposited or sputtered upon the substrate formed by the diaphragm, the resistance of the thin film changing in direct relation to the degree of strain placed upon the film as the diaphragm is distorted. In this case, the strain-sensitive film is flanked on each side by a conductive coating (which may be deposited on the diaphragm by sputtering, vacuum deposition or the like), the two conductive coatings thereby forming electrical connections to the strain-sensitive layer along a major portion of the layer's peripheral boundary.

In a further preferred arrangement, a plurality of strain-sensitive coatings are applied to the diaphragm at locations on the diaphragm having different frequency response characteristics. Accordingly, each of the different thin film regions respond to the acoustical energy impinging upon the diaphragm with different frequency response characteristics, thus making possible the construction of a transducer assembly whose frequency response characteristics may be shaped as desired.

These and other objects, features and advantages of the present invention will be more clearly understood through a consideration of the following detailed description. In the course of this description, reference will frequently be made to the attached drawing in which:

FIG. 1 is an exploded, perspective view of a simple microphone embodying the principles of the present invention;

FIG. 2 is a side, cross-sectional view of the microphone shown in FIG. 1;

FIG. 3 is a plan view of the diaphragm illustrating the manner in which this diaphragm may be connected to an electrical sensing circuit;

FIG. 4 is a side, cross-sectional view of the diaphragm shown in FIGS. 1 through 3 illustrating the placement of the annular corrugations thereon;

FIG. 4A is an enlarged, cross-sectional view of a single corrugation on the diaphragm shown in FIG. 4;

FIG. 5 is a top view of a ribbon-type diaphragm transducer embodying the principles of the invention;

FIG. 6 is a side view of the ribbon-type diaphragm shown in FIG. 5;

FIG. 6A is an enlarged, cross-sectional view of a portion of the ribbon-type diaphragm shown in FIG. 6;

FIG. 7 is a top view of an alternative ribbon-type transducer embodying the invention;

FIG. 8 is a side view of the transducer shown in FIG. 7;

FIG. 8A is an enlarged, cross-sectional view of a portion of the transducer shown in FIG. 8;

FIG. 9 is a side view of the transducer shown in FIG. 8 with the ribbon element in flexed position;

FIG. 10 illustrates the manner in which an active transistor element may be integrally combined with the strain-sensitive coated diaphragm according to the invention; and

FIG. 11 illustrates an alternative arrangement for integrally incorporating a transistor element into the transducer.

In FIG. 1 of the drawings, there is shown an exceedingly simple microphone embodying the principles of the invention which comprises only three principal elements: a resonator indicated at 11; a diaphragm indicated at 12; and a rear case indicated at 13. The resonator 11 includes a plurality of sound entry apertures as indicated at 14. The rear case 13 is simply a hollow cup for defining a rear resonance volume. The resonator 11 and the rear case 13, when clamped together by retaining bolts 16 and 17 as shown in FIG. 2, firmly hold the diaphragm 12 around its entire periphery.

As illustrated in FIGS. 3 and 4 of the drawings, the diaphragm 12 includes a pair of concentric, annular depressions or corrugations molded or otherwise preformed into the diaphragm. The diaphragm may be constructed from a variety of resilient materials; however, the selected material should be electrically nonconductive or, if conductive, should be coated with an insulating layer to isolate the several conductive layers to be applied to the surface of the diaphragm. As shown in the enlarged view of FIG. 4A, one entire surface of the diaphragm may be coated with strain-sensitive material such as cadmium sulfide by known techniques such as vacuum deposition or sputtering.

The ridges of the annular corrugations constitute those regions of the diaphragm which will undergo maximum bending. Therefore, only those regions of the diaphragm need be coated with strain-sensitive material although the entire surface may be coated as indicated at 19 in FIG. 4A in order to simplify the construction process. A conductive coating is then applied to the entire surface of the diaphragm with the exception of the ridges of the corrugations 20 and 21 and the three isolating, insulating strips 27, 28, and 29 indicated in FIG. 3. The regions constituting the strips 27 through 29 and the corrugations 20 and 21 may be masked during the application of the conductive coating. The annular corrugations 20 and 21 and the strips 27 through 29 serve to separate the conductive coating into three distinct and separate regions **31**, **32**, and **33**. The region **32** which separates the smaller annular corrugation **21** from the outer corrugation **20** has been crosshatched to point up this separate relationship, although, of course, there is no difference in actual appearance since the entire surface of the diaphragm is covered by the protective coating **34** seen in FIG. 4A.

As seen in FIG. 3, the strain-sensitive material deposited at the annular corrugation **20** separates conductive region **31** from the outer conductive region **33**. Similarly, the strain-sensitive material deposited on corrugation **21** separates region **32** from the central region **31**. The conductive region between strips **27** and **28** connects the central region **31** to a peripheral tab **41** which extends outwardly from the edge of the diaphragm **12**. Similarly, the insulating strips **28** and **29** define a conductive strip therebetween for connecting the intermediate region **32** to the tab **42**. Tab **43** is directly connected to the peripheral conductive region **33**.

As will readily be understood by those skilled in the art, the impedance which would be measured between tabs **41** and **42** is the impedance of the electrical path through the strain-sensitive thin film applied to the annular corrugation **21**. Similarly, the resistance appearing between tabs **42** and **43** is a measure of the resistance of the thin film applied to the outer circular corrugation **20**. A source of an electrical potential **50** may be connected in series with a resistance **51** between tabs **41** and **42**. In like fashion, the source **50** may also be connected through a resistance **52** to the tabs **42** and **43**. The magnitude of current I_1 flowing through resistance **51** is a direct measure of the resistance exhibited by the strain-sensitive thin film applied to the inner corrugation **21**. Thus the voltage E_1 appearing across resistance **51** is likewise directly related to the resistance of the film at corrugation **21**. In like fashion, the current I_2 produces a voltage E_2 across resistance **52** which is directly related to the magnitude of the resistance of the thin film applied to the outer circular corrugation **20**.

The diaphragm **12** shown in FIGS. 1 through 4 flexes in response to incident acoustical or low-level pressure variations. By way of illustration, a pressure wave indicated by the arrow P in FIG. 4 tends to force the diaphragm to flex downwardly, causing strain to be applied to the thin film layer on corrugation **20**. This fluctuation in strain alters the resistance of the thin film layer to produce a consequent voltage variation across the resistance **52** shown in FIG. 3. Thus, the vibratory motion of the diaphragm in response to acoustical pressure waves causes consequent electrical voltage variations across the sensing resistors **51** and **52**.

Because the smaller, interior region **31** of the diaphragm **12** will tend to respond more readily to high-frequency acoustic waves than will the outer regions of the diaphragm, the variations in the voltage E_1 will tend to have a larger magnitude at high frequencies than does the voltage E_2. Conversely, the signal voltage E_2 will respond more readily to low frequencies. As will be appreciated by those skilled in the art, these two voltages may be combined additively, subtractively, or in a selected phase relationship to provide a selected overall frequency response characteristic. For more specialized applications, diaphragms having different shapes and sizes may be employed with separate strain-sensitive sections connected in series or in parallel. These sections may be electrically independent as in the embodiment shown in FIG. 3, the combining if required being done in the ancillary electrical network. In addition, known frequency discriminating networks may be employed in conjunction with the plurality of transducer sections to further shape the frequency response of the overall transducer.

A further embodiment of the invention is shown in FIGS. 5, 6 and 6A. In this embodiment, the diaphragm takes the form of a preshaped ribbon wherein the strain-sensitive material is deposited as a thin film at the bending point as illustrated in the enlarged view of FIG. 6A. The ribbon itself may be constructed of glass, Mylar, Teflon, or the like, to provide an inherently insulating substrate for the strain-sensitive and conductive coatings. The strain-sensitive material **60** is applied at the bending points on a single side of the diaphragm and each is flanked by a metallic coating as indicated at **61** and **62** in FIG. 6A. As an acoustical wave impinges upon and flexes the ribbon shown in FIG. 6, each of the strain-sensitive layers is stressed in the same way. This follows because, as the angles indicated at A which form the upper V-shaped bending points tend to become more obtuse, the angles indicated at B at the bottom become more acute. Thus, with a net downward pressure force applied, the materials applied at both the upper and lower bending points are subjected to compression. The multiplicity of strain-sensitive elements are accordingly connected in a "series aiding" relationship along the length of the ribbon. The use of a conductive coating between the points of maximum bending minimizes the resistance of the transducer while maximizing its sensitivity.

An alternative ribbon-type diaphragm is illustrated in FIGS. 7, 8, 8A and 9 of the drawings. The ribbon diaphragm comprises two end sections **70** and **71** which are anchored in a support medium and a central section **73**. The underside of the end of each ribbon section is bent upwardly and affixed by a suitable adhesive flush against the underside of the adjacent section, thus forming a pair of upwardly extending junctions **74** and **75**. It should be noted that the ribbon diaphragm of this alternate construction may also be formed as a single integral piece. The strain-sensitive coating is then applied to the arcuate end portions **76** and **77** of the central section as illustrated in the enlarged view of FIG. 8A. As may be appreciated by a comparison of FIGS. 8 and 9 (showing the ribbon in its normal and flexed positions respectively), maximum bending takes place at these arcuate end portions.

In the enlarged view of FIG. 8A, the details of the strain-sensitive structure of the ribbon transducer are shown. A piezoelectric strain-sensitive film (e.g., cadmium sulfide or cadmium selenide) may be coated on a flexible ribbon substrate **79**, such as Mylar, Kapton or anodized aluminum foil. A conductive metallic film **80** is then placed over the strain-sensitive coating **78** except for the narrow strip region indicated generally at **77**. A protective coating **81** (such as silicone monoxide) overlays the entire surface of the ribbon, in order to reduce the effects of humidity. This can be further improved by sealing with a thin coat of epoxy over the active area.

FIG. 10 of the drawings illustrates a third application of the principles of the invention to provide an "active" transducer; that is, a transistor having an integrally incorporated source of gain. A strain-sensitive coating **82** is applied at a point of maximum bending on a flexible diaphragm **83**, only a portion of which is shown in FIG. 7. The strain-sensitive layer **82** is preferably composed of cadmium sulfide and is flanked on each side by metallic coatings **84** and **85** and is covered by a thin insulative layer **86** such as silicon monoxide. A still further conductive metallic coating **87** is supplied over the thin insulative layer **86**. The conductive coatings **84**, **85** and **87** are preferably aluminum and the diaphragm substrate **83** is made of a flexible insulating material. A conductor **91** is coupled to the metallic layer **85** while a conductor **92** is connected to layer **84**. A biasing or "gate" conductor **94** can be connected to the top layer **87**. The path separating conductors **91** and **92** is the transconductive path for the device while a bias voltage is developed on conductor **94** which acts as the gate. The active transistor illustrated in FIG. 10 combines strain sensitivity with power gain and is basically similar in structure and function to the so-called "MIPS" (metal-insulator-piezoelectric-semiconductor) transistor described in the article "Transducer Action in a Metal-Insulator-Piezoelectric-Semiconductor Triode" by R. S. Muller and James Conragan, Vol. VI, No. 5, Applied Physics Letters, Mar., 1965. The spacing between the aluminum layers **84** and **85** should be in the neighborhood of 25 microns; the thickness of the strain-sensitive cadmium sulfide film **81** should be approximately 3 microns; and the thickness of the silicon monoxide coating **86** separating the gate layer **87** from the strain-sensitive layer **82** should be approximately 500 angstroms. A very thin coating of epoxy can be placed over the active area to enhance the resistance of the element to the effects of humidity.

FIG. 11 of the drawings shows still another mode of incorporating gain into the transducer.

A flexible substrate **100** (of the type discussed in conjunction with FIGS. 4 and 10) is coated with a piezoelectric film **101**. A conductive layer of aluminum at **102** provides the "-source" for the unit while a second aluminum film layer **104** provides the "drain" electrode. A third layer of aluminum **105** is maintained in spaced relation from both the piezoelectric layer **101** and the source and drain layers **102** and **104** by a silicon monoxide coating indicated generally at **110**. As before, this arrangement forms a MIPS transistor. The gate layer may be left unconnected ("floating") or may be connected to a biasing voltage source to provide gain adjustment capability.

It is to be understood that the embodiments of the invention which have been described are merely illustrative of applications of the principles of the invention. Numerous modifications may be made by those skilled in the art without departing from the true spirit and scope of the invention.

What is claimed is:

1. A transducer for converting acoustical pressure variations into an electrical signal which comprises, in combination,

a resilient electrically nonconductive diaphragm member mounted for bending motion in response to the impingement of low-level pressure waves, said diaphragm having at least one undulating region defined there along,

a thin coating of strain-sensitive material having piezoelectric properties deposited on said region, said material having an electrical property which varies as said diaphragm undergoes said bending motion,

a biasing conductor on said diaphragm and spaced apart from said strain-sensitive material by a thin insulator such that said transducer has an integrally incorporated source of gain, and

means for sensing the variation in said electrical property.

2. An arrangement as set forth in claim 1 wherein said strain-sensitive material is flanked on both sides by first and second electrically conductive metallic layers respectively and wherein a third metallic layer comprising said biasing conductor overlays said strain-sensitive material, said third layer being disposed in spaced apart electrically insulated relation to said strain-sensitive material and to said first and second layers.

3. A transducer for converting acoustical pressure variations into an electrical signal which comprises, in combination,

a flexible diaphragm having first and second annular concentric spaced-apart corregations defined thereon,

first and second thin coatings of a strain-sensitive material deposited over said first and second corregations respectively, said material having an electrical property which varies as said corregations are distorted due to the bending of said diaphragm in response to said pressure variation,

a first conductive coating deposited between said first and second strain-sensitive coatings and electrically contacting both first and said second strain-sensitive coatings, a second conductive coating deposited adjacent said first strain-sensitive coatings and electrically contacting said first strain-sensitive coatings and a third conductive coating deposited adjacent said second strain-sensitive coating and electrically contacting said second strain-sensitive coating, and

means for sensing the variation in said electrical property of said first and second strain-sensitive coatings.

4. A combination as set forth in claim 3 wherein the electrical impedance of said material varies in relation to the strain applied thereto.

5. A combination as set forth in claim 3 wherein the relative distortion of said first and second corrugations varies with changes in the frequency of said acoustical pressure variations.

6. A transducer for converting acoustical pressure variations into an electrical signal which comprises, in combination,

a resilient electrically nonconductive diaphragm member mounted for bending motion in response to the impingement of low-level pressure waves, having at least one undulating region defined there along,

a transistor amplifier integrally formed on said region including a source electrode, a drain electrode separated from said source electrode by a thin coating of strain-sensitive piezoelectric material having an electrical property which varies as said diaphragm undergoes said bending motion and a gate electrode spaced apart from said strain-sensitive material and said source and drain electrodes by a thin insulating material, and

means for sensing the variation in said electrical property.

7. A transducer for converting acoustical pressure variations into an electrical signal which comprises, in combination,

a flexible ribbon diaphragm member mounted for bending motion in response to the impingement of low-level pressure waves, having a plurality of undulating regions defined there along,

a plurality of coatings of a strain-sensitive material deposited over said regions on one side of said diaphragm said material having an electrical property which varies as said regions are distorted due to the bending of said diaphragm in response to said pressure variations, and

means for sensing the variation in said electrical property of said coatings.

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