

[54] METHOD OF MAKING ELECTRET
TRANSDUCERS

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111 E; 156/247; 252/63.2

[56] References Cited

UNITED STATES PATENTS

2,618,698	11/1952	Janssen	179/100.41
3,449,093	6/1969	Baxt et al.	307/88 ET
3,068,564	12/1962	Wiedt	29/423
3,316,620	5/1967	Stewart	307/88 ET

FOREIGN PATENTS OR APPLICATIONS

610,297 4/1946 Great Britain 179/111 E

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[57]

ABSTRACT

Dielectric material is polarized or electrified so as to form an electret which is suited for use in a microphone or other transducer by the method which includes the steps of forming an intimate contact between the dielectric material and a conductor material and then separating these when the dielectric is cool, preferably while maintaining an electrical connection between conductors on the two surfaces of the dielectric during the separation step, without the employment of an external electric field.

6 Claims, 6 Drawing Figures

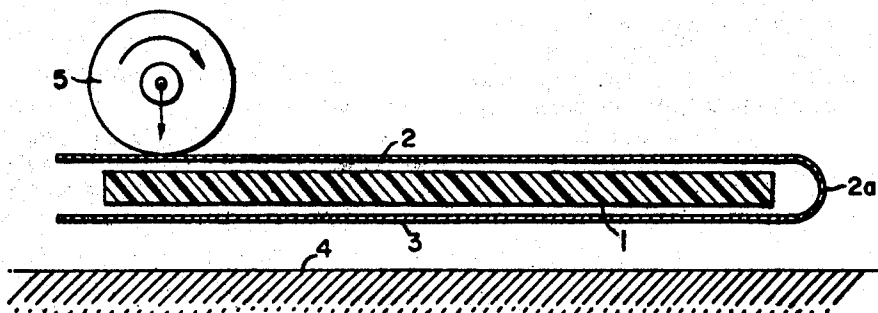


FIG 1.

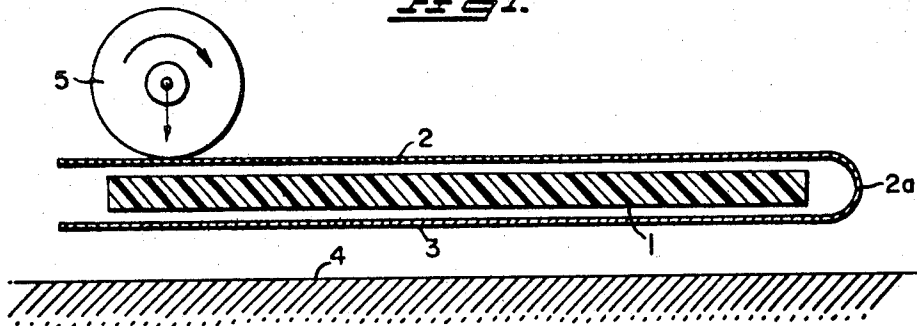


FIG 2.

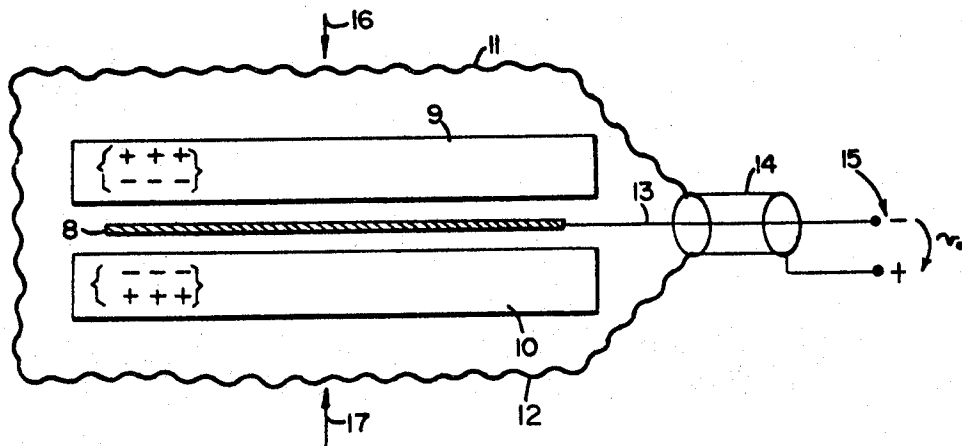
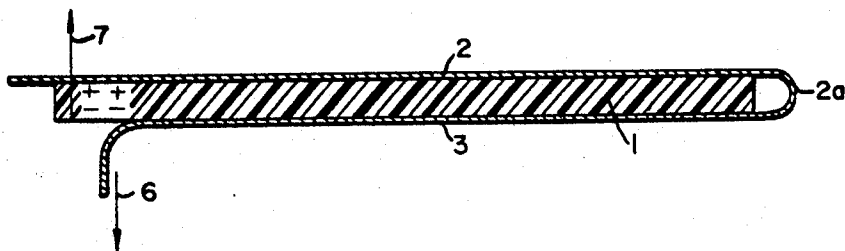
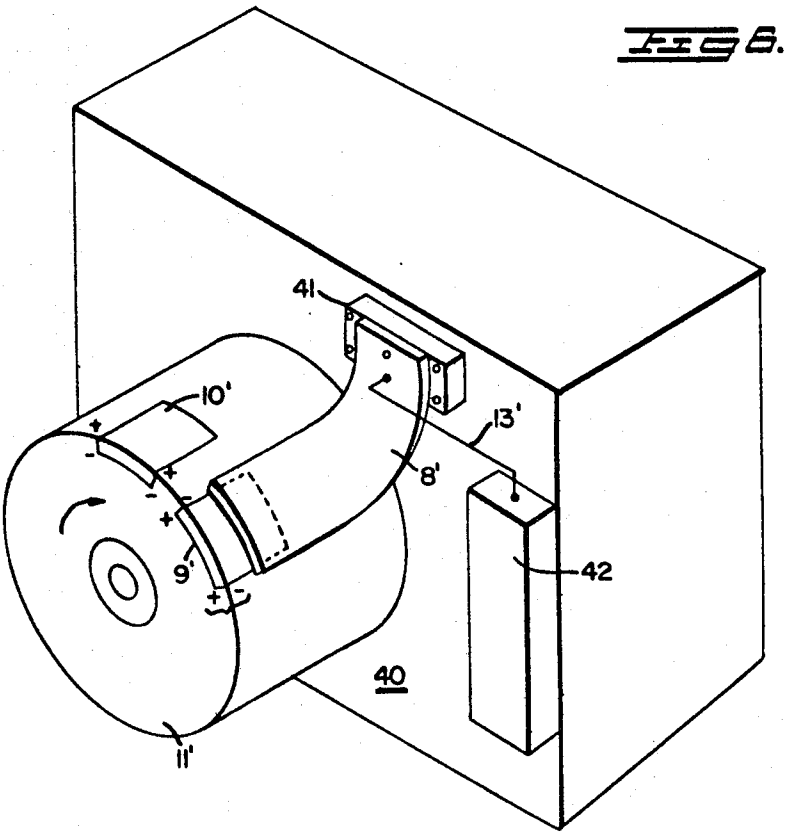
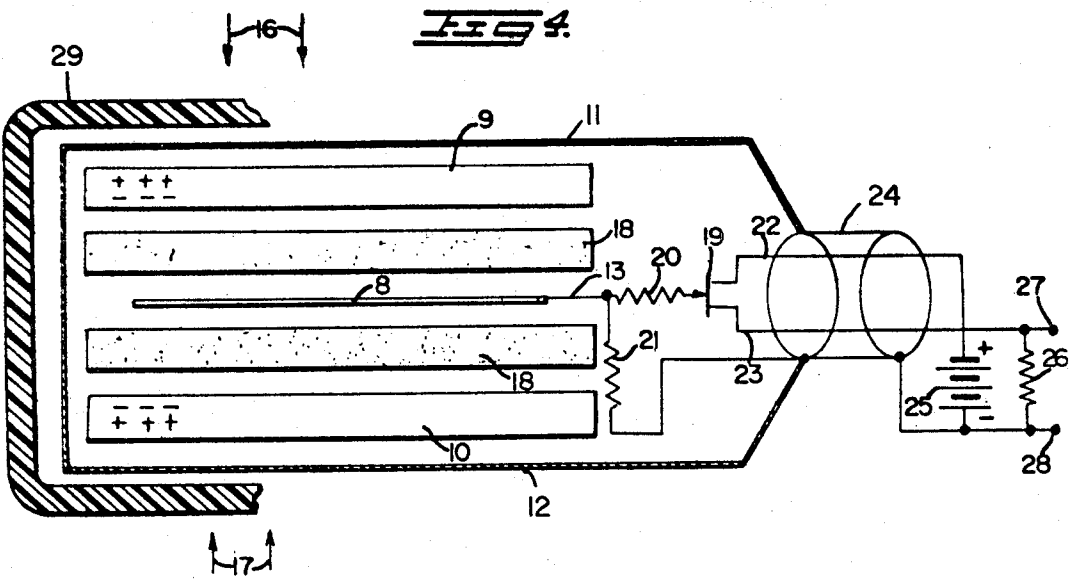


FIG 3.

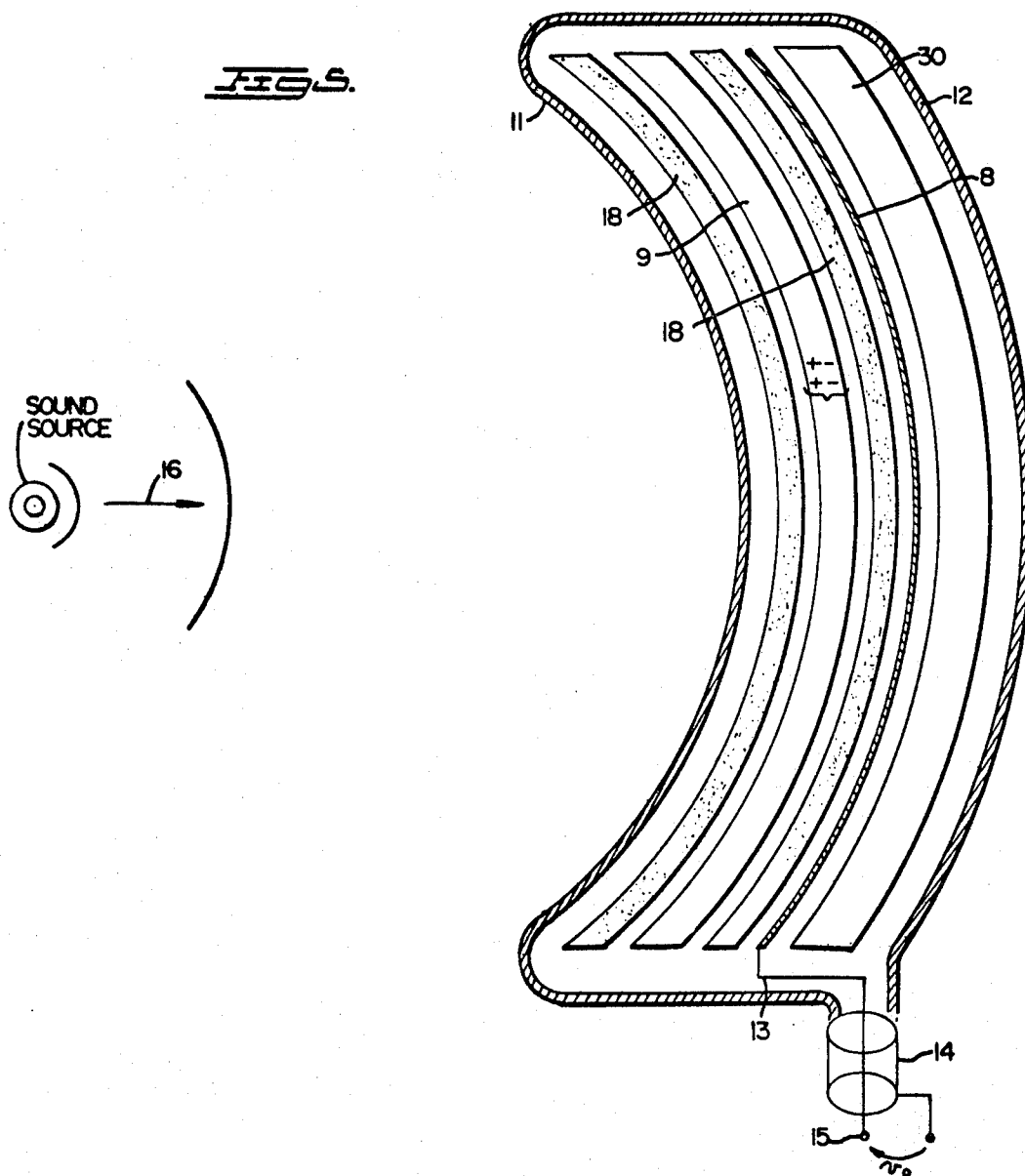


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FIG. 5.



METHOD OF MAKING ELECTRET TRANSDUCERS

This invention relates to the method of production of electret or polarized dielectrics, their structure, and structures embodying the use of such electrets or polarized dielectrics, such as hydrophones or microphones and a position or motion sensing transducer for use in positioning, timing, or measuring the motion of machine members, or counting events in a machine.

In accordance with the principles of this invention it has been found that electrets can be produced which have greater polarization potential and cost less in manufacture than previously known means. It has also been found that hydrophones, microphones, and position or motion sensing transducers can be constructed which have characteristics superior to previously known devices.

The electret of the present invention is a dielectric material treated so that it appears to have a source of direct current potential located in between its two insulating surfaces. A hydrophone or microphone is made by placing two conducting sheets in proximity to the opposite surfaces of the electret in such a manner that one or both may move with respect to the electret when an external hydraulic or pneumatic force is applied. The relative change in position of the electret and the conductor causes a potential change to appear between the two conductors. This is the transducer output voltage. A position or motion sensing transducer can be made by arranging for the passage of an electrode over an electret, or series of oppositely polarized electrets.

In accordance with the principles of this invention it has been found experimentally that relatively large output potential changes are obtained when relatively small forces are exerted on simple structures. The potential developed is dependent primarily on the change in position of the sensitive members. This is to be contrasted with more conventional transducers wherein the output potential is primarily dependent upon the force exerted as in the piezo-electric effect, or upon the rate of change of position of a member, as in electromagnetic devices utilizing Faraday's law. The structures constructed according to the teachings of this invention are typically highly resistant to shock. This is readily achieved, for the electret is flexible and tough; not a crystalline structure as in piezo-electric structures aluminum sheets 2 and 3 are electrically connected by conductor 2a, which may be a fold in the aluminum sheet or a longer wire.

When used in a hydrophone or microphone the output potential change tends to increase as excitation frequency diminishes; constant incident sound intensity assumed.

Other objects and advantages of this invention will be apparent from the following description taken in conjunction with the accompanying drawings.

In the drawings:

FIG. 1 shows a schematic representation of a general method for joining the dielectric to be polarized in intimate contact with conductors.

FIG. 2 is a schematic representation of a means for separating the dielectric material from the conductor on one side.

FIG. 3 is an outline of a basic method for making a transducer.

FIG. 4 shows another method for making a transducer. This is more adaptable to operation under conditions of high external pressure.

FIG. 5 shows a method for making a directional hydrophone or microphone.

FIG. 6 shows means for making a position sensing transducer.

A method for polarizing a dielectric to form an electret is described first. The first part of the process is illustrated in FIG. 1 of the drawings. It will be seen that the means for joining the dielectric 1 to the thin sheets of metal 2 and 3 include a source of heat 4 and a source of rolling or sliding pressure 5 which forces the metal sheets into intimate contact with the dielectric at high temperature. Good samples have been prepared using polyethylene plastic sheet marketed by the Union Carbide Corp. under the trade name "ZENDEL", for dielectric 1. A sample of "ZENDEL" six thousandths of 1 inch (6 mils) and measuring 6 inches on a side may be placed in between the folded over portions of a sheet of aluminum foil 2 and 3 which measures seven inches by fourteen inches. A suitable material is marketed commercially by the Reynolds Metals Company under the trade name "REYNOLDS WRAP." It is labeled pure foil, heavy duty. The "ZENDEL" sheet 1 is located in the center of the area of aluminum sheets 2 and 3 so that the metal completely covers the dielectric "ZENDEL" sheet on both sides.

The sandwich of the dielectric and metal is then placed flat in the center of a source of heat 4. It has been found that good results are obtained using a commercially available electric frying pan having temperature regulation means set for 225° Fahrenheit. The sandwich 1, 2, 3, is then pressed firmly against the flat and smooth heat source 4, using pressure source 5 to force the component parts together. It is preferable to apply a uniform pressure progressively along the surface of the sandwich as shown in FIG. 1, so that air is not trapped in the sandwich. Soft paper towel wads may be used in lieu of a rolling pressure source 5. One wad is used to hold the sandwich in place on the heat source 4 while the other is rubbed with a uniform pressure across the surface of the exposed aluminum foil 2. About twenty pounds force is applied to a two square inch area. Then the holding piece is moved to a new spot and the operation repeated until all parts of the aluminum foil surface 2 appears smooth and well adhered to the dielectric 1. The sandwich is then removed from the source of heat 4 and allowed to cool slowly. This completes the process of establishing an intimate contact between the dielectric surfaces and metal surfaces.

The final steps in polarizing the dielectric to form an electret are shown in FIG. 2 of the drawings. The cooled sandwich 1, 2, 3, is separated as shown in FIG. 2. First, metal layer 3 is pulled progressively away from dielectric 1 by forces 6 and 7. Force 7 is applied to both the upper conductor 2 and the dielectric 1. Force 6 is applied to only conductor 3. Pulling continues until the whole of the bottom conducting sheet 3 has been separated from the dielectric 1. Conductor 2 may then be left on the dielectric, or separated from it. If it is separated it is preferred that the surface of the dielectric 1 not touch any conducting or high dielectric constant material surface during pulling, as this tends to increase an opposing polarization.

It has been found experimentally that the negative charge or potential exists on the surface of the dielectric 1 which was first separated from the metal surface. If 3 is pulled first, the side of 1 which was adjacent to 3 will be negative, but if alternatively 2 is first pulled away from 1, then the side or surface of 1 which was next to 2 will be negatively polarized. This effect can be used to write a binary code into a dielectric sheet. The metallic surfaces can be pulled away from the dielectric in narrow strips first on one side of the dielectric and then on the other, in accord with the code.

The metallic surface is considered to be rich in free electrons, and it is thought that these become embedded and trapped in the surface of the dielectric when an intimate bond is made. When the bond is destroyed some of these electrons are thought to remain in the surface of the dielectric. However, the very substantial electrostatic potential resulting as the bond is broken pulls many of the electrons trapped in the dielectric back to the metal. This withdrawal effect is minimized by bonding conductor surfaces to both surfaces of the dielectric, and maintaining a good electrical connection 2a between the metal sheets bonded to the upper and lower surfaces. Then, upon breaking the first surface bond, the associated electrostatic potential acts also through the dielectric to hold the electrons in the surface of the dielectric.

This theory is supported by the observation that some degree of polarization can be achieved by bonding only one conductor sheet to only one surface of the dielectric, or by insulating the two metal sheets if both surfaces of the dielectric are bonded to metal, and then breaking the dielectric to metal bond. However, considerably greater polarization results if the two metal sheets bonded to both surfaces of the dielectric are connected electrically during the first separation.

This theory is also supported by the observation that thicker dielectrics exhibit a lesser electric field strength than thinner dielectrics when treated in the same way, using the same materials. The polarization voltage produced in thick samples is greater than that in thin samples, but the voltage per unit thickness is less in the thick samples.

The following results of experiments in using this process will serve to illustrate the value of this invention.

A "ZENDEL" sample having a thickness of 6 mils was polarized to a potential of about 960 volts, or 64,000 volts per centimeter. A similar sample was polarized to 1,280 volts, or 85,000 volts per centimeter. Then three layers of "ZENDEL" were stacked one above the other and processed in the same way. The resulting polarization was 2,940 volts, or 65,000 volts per centimeter. Tripling the thickness of the dielectric more than doubled, but did not triple, the polarization potential.

In still another experiment a sheet of commercial Isinglass was treated in the same way and gave 2,500 volts polarization in a thickness of 25 mils, or 40,000 volts per centimeter.

The polarization voltage is relatively stable with time using the materials and process noted above. Microphones tested several months after manufacture exhibit about the same sensitivity as when originally produced. It appears that the stability is enhanced by keeping the electret sandwiched between conducting sheets. Normal room temperature storage or use is permissible, but elevated temperatures tend to reduce polarization.

Exposure to a highly ionized gas or liquid tends to reduce the polarization voltage of the electret.

A "ZENDEL" sample polarized over a year ago using a less efficient method still exhibits over 100 volts polarization in 6 mils thickness. The polarization has dropped three DB or less in the last 10 weeks. Other samples of "ZENDEL" and isinglass have maintained their original polarization with 6 DB or less for periods of 10 to 14 weeks. All were stored between loose sheets of aluminum foil, and exposed to an ambient air which is high in salt laden humidity. It is expected that better results will be obtained if the humidity is excluded.

The cross section of an elementary transducer structure is illustrated in FIG. 3 of the drawings. In this structure a central metal plate 8 is completely covered on both surfaces by polarized dielectric sheets 9 and 10. The negative surface of each electret 9 and 10 is positioned next to the central electrode 8. The outer electrodes 11 and 12 may be one continuous sheet of reasonably thin and flexible metal such as the aluminum foil used as 2 and 3 in preceeding sections. This outer electrode should be in loose contact with electrets 11 and 12. This can be accomplished by wrinkling the foil, and then partially smoothing it. Conductor 13 is electrically connected to electrode 8. Shield conductor 14 is electrically connected to electrodes 11 and 12. Shield 14 preferably surrounds, but is insulated from conductor 13 in accordance with usual microphone cable practice. Output potential will be measured at terminals 15.

A momentary increase in pressure 16 and 17 will cause a force to be exerted on outer conductors 11 and 12, pressing them more tightly against electrets 9 and 10. This increases the coupling of the electrodes to the electrets by reducing the air gap between electrodes and electrets. The capacitance of that part of the circuit in series with the polarization voltage within the volume of the electrets increases, and the potential across the capacity associated with the output conductors 13 and 14 increases. The output voltage measured at terminals 15 will increase, conductor 13 becoming more negative with respect to conductor 14.

The sensitivity of the structure depends upon the details of the method used in construction and the polarization potential of the electrets. A 6 by 10 inch assembly formed and coated so as to be operable under water was found to have a sensitivity at voice frequencies in the order of 60 DB below one volt per micro bar when used in air. The quality of voice reproduction is good.

If the structure of FIG. 3 is made very flexible and the output observed with an electrometer which has direct current response and an input resistance in the order of 10^9 to 10^{12} ohms it will be found that the output potential change at terminals 15 is much greater than 20 volts when electrodes 11 and 12 are compressed a distance of 1/1000th of 1 inch, or less, moreover a weight of 1/100 ounce acting over an area of 10 square inches will produce an output in the order of 8 volts. This corresponds to a very low frequency sensitivity of about 1 volt per microbar. The time constant of output voltage decay is several seconds.

Few transducers are capable of subaudio frequency response, and those that are tend to be physically delicate, unable to survive the shock of a hammer blow or being dropped from a great height. This electret assembled with suitable electrodes will withstand such treatment.

A more rugged transducer is sketched in FIG. 4 of the drawings. The basic approach is the same as that shown in FIG. 3 except that the physical structure is stiffened, and a field effect transistor has been added within the structure to minimize the effect of stray capacity loading and cable noise.

In FIG. 4 the central electrode 8 is a metal sheet surrounded on both surfaces by compliant, compressible material 18. The electrets 9 and 10 are laid over the top layer of compressible matter 18 and also under the bottom layer of 18. The negatively polarized surface of both electrets 9 and 10 is faced toward the central electrode 8. The outer electrodes 11 and 12 are relatively thin and flexible. Sheet steel may be used for this purpose. The dimensions of one surface may be 6 inches by 10 inches, but this is adjusted to suit the specific need. The compliant material 18 is preferably thin, in the order of 10 mils thick, but may be one-fourth inch thick or more if required. Sensitivity is increased with thin net material, sensitivity also increases as the material becomes more compliant. The lower outer electrode 12 may be made of heavy, solid material if sensitivity on only one side is desired. The edges are sealed by extending and joining the upper and lower electrodes 11 and 12, or by providing a rigid side frame and sealing 11 and 12 to this.

The positions of electrets 9 and 10 may be exchanged with the positions of compressible material 18, so that 18 is next to the outer electrodes and electrets 9 and 10 are next to the central electrode sheet 8.

In operation a pressure at 16 and 17 causes electrodes 11 and 12 to deform inward, compressing material 18. This increases the capacity between the inner and outer electrodes 8, 11 and 12 through the electrets 9 and 10. This causes the potential of 8 to become more negative with respect to 11 and 12.

If the output conductor 13 connected to central electrode 8 were brought to the point of use through a long cable (14 in FIG. 3) the resulting capacity would act as a load on the output signal. It would divide the signal down by the ratio of the capacity of the transducer (Capacitance of 8 to 11 and 12) to the capacity of the cable. Since a long cable can have very substantial capacity this effect can be serious. In addition, it is found that most shielded cables produce a noise output voltage when bent, flexed, pounded, etc. This too can be substantial unless the transducer is a low impedance source.

To overcome these practical difficulties it is desirable to insert a field effect (FET) or metal-oxide-silicon (MOS) transistor 19 within the overall transducer structure formed by the closure of electrodes 11 and 12. FIG. 4 illustrates the use of an N channel, P gate FET transistor such as that marketed commercially by Siliconix Inc. under the label U183. This device has a gate lead, a source lead and a drain lead. A 100,000 ohm resistor 20 is connected in between the gate lead of 19 and transducer output lead 13 to protect the gate from high energy pulses produced by the transducer when it is subject to abuse such as high shock. The gate of 19 is established at an average bias potential equal to the potential of the outer electrodes 11 and 12. These are connected electrically to the outer shield of output cable 24. This is accomplished by 1,000 megohm resistor 21, which is connected between conductor 13 and shield 24. The drain lead of FET 19 is connected to conductor 22 which is one of the two

shielded leads surrounded by conductor 24. The source terminal of FET 19 is connected to conductor 23 which is the other shielded lead surrounded by 24. The output cable 24 is long enough to reach the point of use of the transducer signals. At this point, or at some other convenient intervening point, the positive terminal of battery 25 or other source of drain potential is connected to conductor 22. The negative terminal connects to 24. A 12 volt potential is convenient. A load resistor 26 is used to carry the source bias current. It is connected from lead 23 to lead 24. Resistor 26 may be 3,300 ohms. The transducer output signal is available between leads 23 and 24, at terminals 27 and 28.

The whole transducer assembly may be surrounded by a relatively thin and flexible plastic jacket 29. A material such as neoprene rubber may be used. This provides protection from a hostile environment.

It will be appreciated by those skilled in the art that many variations on the specific details given above may be used to improve the performance, reduce cost, improve reliability, or meet other needs. Engineering improvements contemplated include use of a compressible material 18 which may also be polarized. On the other hand, mechanical deformations may be placed in the polarized material. If the electret is dotted or ribbed it will act as a compressible substance. Gasses or fluids may be used to augment or replace the compressible material.

The following are the central teachings of this invention:

1. A dielectric is polarized to form an electret.
2. The electret is positioned between two conducting sheets or electrodes in such a way that the capacity between the two electrodes can be changed by the force, pressure, motion, or other event to be translated into an electrical signal.
3. It is generally preferable to change the capacity between the two electrodes by changing the spacing between the electrodes in the path which includes the electret. However, a change in effective area of the electret or electrodes, or the dielectric constant of the material in the gap between electrodes and electret, will have the same effect.
4. The change in output potential in typical transducers is proportional to electrode displacement, not necessarily pressure or force.

For example, it has been found that the compressible material 18 in FIG. 4 may be a soft plastic bag containing air at a pressure just slightly greater than ambient, connected pneumatically to a reservoir of air at the same pressure. The reservoir has a volume much greater than the volume of the space 18. The outer electrode 11 is a freely moving piston of light metal, supported by air sack 18, and electrically connected to support 12 and conductor 24. Then a very small mass or pressure on electrode 11 results in a large displacement of 11, and a large output potential change. A sensitivity of 1 volt per microbar can be obtained in this way. Moreover, the system is differential in nature. A pressure exerted on the external air reservoir connected pneumatically to space 18 will produce an output potential change in the opposite polarity from that due to a pressure on 11.

A sound transducer having good directional properties is shown in FIG. 5 of the drawings. This device is similar in nature to that shown in FIG. 3 and FIG. 4, except that it is formed so that the sensitive portion has

the shape of a section of the surface of a sphere having a radius equal to the distance to the source of sound energy to be observed. A cylindrical section may be used if directivity in one plane is sufficient.

The sensitive portion of the microphone or hydrophone shown in FIG. 5 is the outer electrode 11. This has the spherical surface shape, and is relatively flexible and able to move in response to incident pressure 16. Compliant material 18 may be located on one or both sides of polarized dielectric 9. Central conductor 8 is positioned opposite the face of 9 which has the negative polarity, however, the opposite polarity may be used if convenient. Electret 9 is located in between the surfaces of 8 and 11. Central conductor 8 is located some reasonably large distance away from backup electrode 12, by unpolarized dielectric 30. Both 30 and 12 may be rigid if desired.

Potential changes occur on central electrode 8 as a result of pressure 16 in the same manner as that described in connection with FIG. 3 and FIG. 4. This output signal is made available at the point of use 15 by conductors 13 and 14, which connect to the electrodes 8, 11 and 12, respectively.

It has been observed that the directivity of even a planar (flat) microphone is considerable at the higher audio frequencies.

The effectiveness of this approach is due to the fact that no reflectors are required to concentrate incoming sound energy on a small central detector as in conventional directional transducers. In the form shown in FIG. 5 all sections of the sensitive surface contribute to the output signal power in a coherent fashion. Note that the area of this surface may be very large. This means that the sound power removed from the medium may be substantial, even for a low intensity signal. Moreover, in a hydrophone structure wherein no reflection of signals is required the hydrophone may be made to have very nearly the same velocity of sound propagation as the surrounding water. Then the incident sound wave will be largely unreflected. The presence of the hydrophone will be difficult to detect.

Still another application of the polarized dielectric is shown in FIG. 6 of the drawings. Here the polarized dielectric or electret is used as a position sensing transducer. By way of example, the frame 40 of an internal combustion engine using spark plugs may support a flywheel 11' which functions as the ground electrode and also to support two electrets 9' and 10'. The frame 40 may also mount an insulating block 41 which supports a metallic sheet 8' formed so as to ride just over the flywheel 11'. As flywheel 11' rotates electret 9' will first appear under electrode 8', and electrode 8' will assume a negative potential due to the arrangement of 9' which places the negatively polarized side of 9' facing unit. This pulse may be connected to spark plug electrical pulsing means 42 by conductor 13, and fire the appropriate spark plug. Then as flywheel 11' rotates further around sensing electrode 8' will receive a positive pulse due to the presence of electret 10' directly between the flywheel 11' and electrode 8'; electret 10' being positioned so that the positively polarized surface is adjacent to 8'. This positive signal can be interpreted by the logic of the spark plug pulser 42 as a signal to fire the next cylinder in the firing order. Thus the arrangement of the electrets 9' and 10' on flywheel or timing wheel 11' can be used to form a digital code to dictate the firing order, and commutate the engine's

spark plugs. It will readily be seen that this same arrangement may be used to synchronize electrical events to a variety of mechanical motions, either rotational or translational. Moreover, it can be used as a position transducer in a servo mechanism. In this instance the electronics will drive a motor so as to maintain neutral potential at electrode 8', so that 8' is located midway between the positive and negative electrets 9' and 10'.

This and other arrangements all have the advantage that the output of the sensing element is proportional to the proximity to, or displacement from, the electret, not the rate of change of position, or force applied, as in other more common transducers.

The basic transducer structure shown in FIG. 4 may be modified from the planar form therein to a coaxially cylindrical or spherical form. Then an omni-directional microphone or hydrophone is obtained. On the other hand if such a transducer is placed in a moving fluid the vibrations resulting from the associated Fugoid vortex, formed as the fluid eddies around the sphere, will provide a measure of the velocity of the fluid.

An accelerometer or seismograph may be constructed using the basic transducer structure shown in FIG. 4. A substantial mass is attached to one electrode, and the other is mechanically fastened to a reference of ground plane.

Improved medical instruments such as stethoscopes may be constructed using the basic structure shown in FIG. 4. Considerably improved response to slowly varying signals will result from the sensitivity of this transducer to displacement of the electrodes. This is thought to be valuable since the output is increasing in the very low frequency region where transistor noise increases markedly, and where most other transducers are least sensitive.

Materials other than polyethylene and isinglass may be used in connection with the process given in connection with FIG. 1 and FIG. 2. Certain acetate plastics, mylar, and others are known to be polarizable. Moreover, the intimate contact between metal and dielectric can be produced by joining two pieces of metal arranged in parallel planes with a film of epoxy or other adhesive. When the bonds between the epoxy or adhesive and metal surface are broken the adhesive is polarized.

It is also observed that a variety of materials poses a polarization as a result of their past treatment. Substantial polarization has been observed in certain anodic films on aluminum. Moreover, the finished transparency marketed by the Xerox Corp. under the trade name "ZELAR" poses a substantial polarization in some instances.

What is claimed is:

1. The method of polarizing a dielectric to form an electret, which includes the placing of a sheet of dielectric material of such thickness as to be readily vibratable between relatively thin metallic sheets of such thickness as will permit them to be readily peeled from an attached surface, connecting said metallic sheets in electrical connection, applying pressure and heat to said dielectric and metallic sheets in amounts of heat and degree of pressure regulated in accordance with the known properties of the dielectric material and the metallic material to provide an intimate bond between these materials sufficient to initiate the creation of electric voltage in the dielectric, allowing the sheets to

cool and peeling said metallic sheets from said dielectric sheet to prevent frictional sliding motion between the said dielectric and metallic surfaces.

2. The method of polarizing a dielectric to form an electret as claimed in claim 1, wherein the dielectric material is a readily vibratable sheet of polyethylene and the material is aluminum foil of the normal market thickness.

3. The method of polarizing a dielectric to form an electret as claimed in claim 1, wherein the dielectric material is a readily vibratable sheet of isinglass and the metallic material is aluminum foil in sheet form of normal market thickness.

4. The method of polarizing a dielectric to form an electret as claimed in claim 1, which includes the placing of a readily polarized adhesive material between the sheets of dielectric and metallic material to enhance the physical bonding of the material of the sheets.

5. The method of polarizing a dielectric as claimed in claim 1, wherein the step of separating consists of peeling part of a first selected said metallic material from the associated said surface of said dielectric material in such manner as to prevent frictional sliding motion between the dielectric and metallic material while maintaining electrical connection between said first selected metallic material and said metallic material on the op-

posite side surface of said dielectric material, then peeling part of said metallic material from said opposite surface while still maintaining said electrical contact, and continuing in this fashion until a digital pattern of a desired form has been produced in the said surface of said dielectric material. the dielectric

6. The method of polarizing a dielectric to form an electret which comprises placing two sheets of dissimilar materials, one of which is a dielectric material in sheet form of such thickness as to be readily vibratable, and the other relatively thin sheet of a metallic material of such thickness as to permit it to be peeled from the dielectric material in a lifting metal sheet distorting action, placing said sheets in flatwise contact with each other, applying heat and pressure of degrees determined by the known determined composition of the dielectric and metallic materials necessary to form a physical bond between said sheets of material to cause an interchange of electron orbits in the atoms and molecules of the dissimilar materials, allowing the sheets of material to cool and then separating the materials by peeling one from the other in such manner as to prevent creation of friction between the sheets of material during the separating operation.

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