

June 25, 1946.

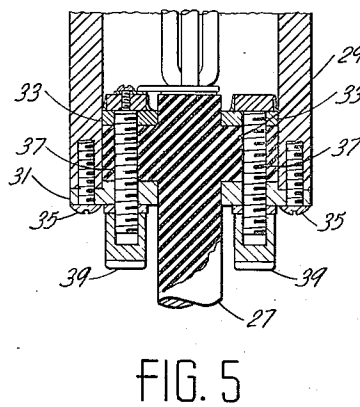
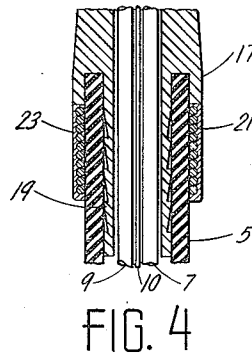
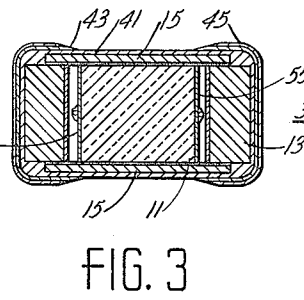
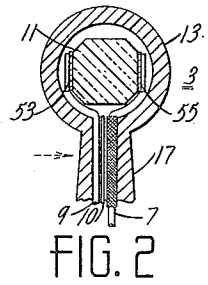
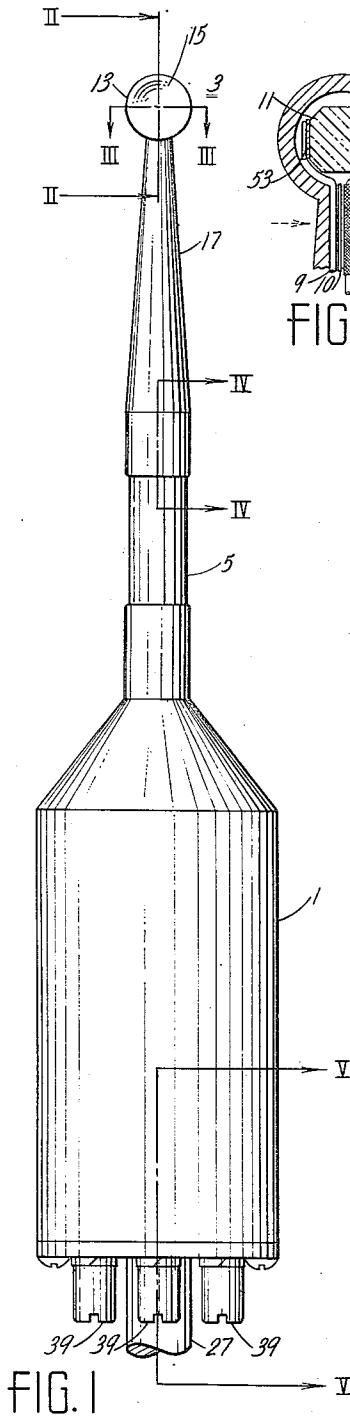
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2,402,531

TRANSDUCER

Original Filed June 4, 1942

2 Sheets-Sheet 1



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2 Sheets-Sheet 2

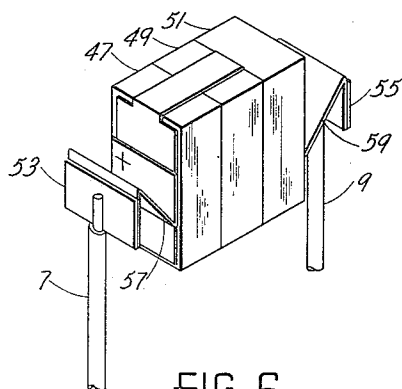


FIG. 6

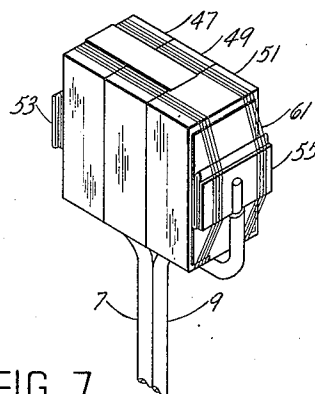


FIG. 7

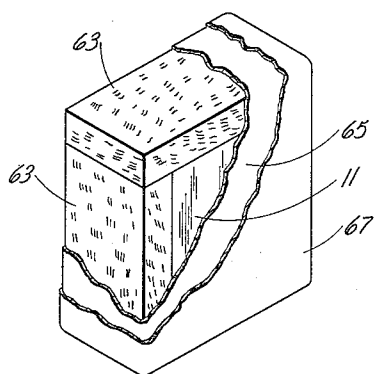


FIG. 8

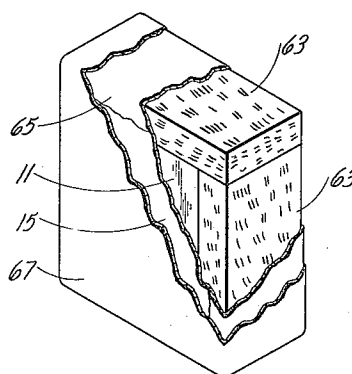


FIG. 9

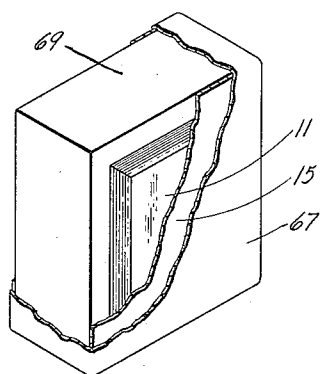


FIG. 10

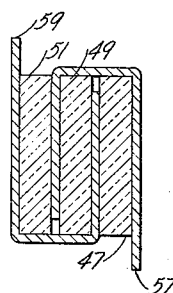


FIG. 11

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UNITED STATES PATENT OFFICE

2,402,531

TRANSDUCER

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Continuation of application Serial No. 445,741,
June 4, 1942. This application March 28, 1944,
Serial No. 528,454

19 Claims. (Cl. 177-386)

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This invention relates to transducers and, more particularly, to receivers and transmitters of the piezoelectric type adapted for operation in a fluid medium such as water or the like.

This application is a continuation of my application Serial Number 445,741, filed June 4, 1942, which is abandoned.

For certain underwater uses, such as sound pressure measuring or the like, it is decidedly advantageous to utilize a sealed, pressure actuated microphone, and it is also desirable that the microphone be substantially non-directional. To secure the non-directional characteristic, the overall physical size of the pressure measuring unit should preferably be less than $\frac{1}{4}$ wave length at the frequency of operation. For example, the spacing between the faces of the diaphragms, between which the crystal section is interposed, should preferably be less than $\frac{1}{2}$ inch for a frequency of 50,000 cycles per second. The active surfaces of the diaphragms, as well, should have a diameter of the same order of magnitude for best results.

When such small dimensions are necessitated, it is not feasible to utilize bolts or screws, nor can brazing or soldering be employed for affixing the diaphragms to the microphone head, because of the destructive action of heat on Rochelle salt crystal elements.

It is, therefore, an object of the invention to provide an improved method of constructing a waterproof housing for a piezoelectric crystal unit.

Another object of the invention is to provide an improved method of attaching a diaphragm or cover-plate to a container under conditions necessitating minimum heat.

It will be appreciated, by those skilled in the art, that the electrical capacitance of a single piezoelectric crystal section, of the usual type and suitable for utilization in a transducer having the dimensions hereinabove mentioned, would be relatively small. The disadvantage of a very small electrical capacitance is that stray capacities of leads and the capacity between the crystal unit electrodes and ground may introduce errors.

Another difficulty is encountered in connecting the small crystal electrodes to the pre-amplifier tube in such manner as to preclude the possibility of strain thereon and breakage thereof during operation.

Further objects, therefore, are to provide an improved composite piezoelectric crystal-element-assembly that shall have much greater capacitance than a single homogeneous element, yet

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shall occupy substantially no more space, and to provide an improved mode of connecting the crystal-electrodes to ancillary apparatus.

In one embodiment of the invention, electrodeposition of a suitable metal is employed for affixing the diaphragms across the opposite ends of a substantially cylindrical frame wherein is disposed one of the improved high capacitance crystal element assemblies. Alternatively, as hereinafter will be explained, the entire crystal housing, including the diaphragms, may be formed by electrodeposition.

It is to be understood that the use of the term "microphone" hereinafter is not intended as a limitation, inasmuch as the invention is applicable also to transmitters.

The novel features considered to be characteristic of the invention are set forth with particularity in the appended claims. The invention itself, however, both as to its organization and its method of operation, together with additional objects and advantages thereof, will be understood best from the following description of certain specific embodiments thereof, when read in connection with the accompanying drawings, in which:

Figure 1 is a life size view in elevation of a submarine compressional wave sending or receiving device of the type to which this invention pertains;

Figure 2 is a view in vertical section of the microphone head, greatly enlarged, taken along a line corresponding to the line II—II in Figure 1;

Figure 3 is a horizontal sectional view, greatly enlarged and dimensionally exaggerated, of the transducer portion of the device, taken along a line corresponding to the line III—III in Figure 1;

Figure 4 is a vertical sectional view, greatly enlarged, of a portion of the device, showing the mechanical connection of the transducer portion thereof to an isolating element;

Figure 5 is a vertical sectional view of the end of the pre-amplifier housing, to which a supporting cable is secured, taken along a line corresponding to the line V—V in Figure 1;

Figures 6 and 7 are perspective views, greatly enlarged, of the improved composite piezoelectric crystal unit, illustrating the preferred manner of connecting the output leads therefrom to the electrodes thereof;

Figures 8, 9 and 10 are views in perspective, exemplifying alternative methods of providing a pressure-responsive piezoelectric crystal unit with a water-proof housing, and

Figure 11 is an enlarged sectional view of a

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composite piezoelectric crystal unit, made in accordance with the invention, exemplifying the electrode arrangement thereof.

In all figures of the drawings, identical elements are similarly designated.

Referring now to Figure 1 of the drawings, a submarine compressional wave sender or receiver, of the general type to which this invention is applicable, includes a cylindrical pre-amplifier tube housing 1 and a piezoelectric crystal element housing 3 supported therefrom by a flexible, waterproof hose 5 through which electrical conductors 7 and 9 extend between a crystal unit 11 and the pre-amplifier tube (not illustrated). A ground connection 10 may also be included. The hose 5, which may be of rubber, or the like, is an isolating element that tends to attenuate mechanical vibrations and impedes the transfer thereof from the housing 1 to the piezoelectric crystal unit which vibrations, otherwise, would interfere with the satisfactory reception of compressional waves by the said unit. The relatively long thin tubular neck between the amplifier housing 1 and the crystal container 3, is specifically designed to permit relatively large separation between those parts to minimize diffraction and reflection errors. The broad combination of pre-amplifier housing and microphone head, as well as certain specific details thereof, together with the circuit connections, are shown and claimed in the pending application for United States Letters Patent, Serial No. 452,906 filed July 30, 1942, in the name of Frank Massa.

As shown in Figures 2 and 3, the crystal unit housing is constituted by a drum-like circular container 13 provided with two oppositely disposed flexible diaphragms or heads 15 the space between which is just sufficient to accommodate the pressure responsive piezoelectric crystal unit 11. For purposes of convenience the crystal unit housing hereinafter will be referred to as a microphone head but it is to be understood that it may be utilized to send as well as to receive compressional waves.

The microphone head is mounted upon and may be integral with a hollow metallic stem 17 that terminates in a serrated nipple 19 which fits into one end of the isolating rubber hose 5 as shown in detail in Figure 4. For the purpose of making a water-tight connection between the nipple and the hose, it is wrapped tightly with copper wire 21. The wire wrapping is spot soldered at a number of points, then rubbed thoroughly with graphite and copper-plated. The electrodeposited metal 23 firmly bonds the turns of the wire wrapping together and to the stem of the microphone head.

The microphone head 3, the stem 17 thereof and the pre-amplifier housing or shell 1 are made from a metal such as brass that resists corrosion.

One end of the pre-amplifier housing 1 is provided with a serrated nipple which fits into an end of the isolating hose and is held thereon by an electroplated wrapping of wire such as was described in connection with Figure 4. Inasmuch as the two nipples are identical and are held to the hose in identically the same manner further illustration is not believed to be needed.

As shown in Figure 5, a shielded cable having an outer rubber covering 27 is anchored into the end of the pre-amplifier housing 1 opposite to the end provided with the hose connection. In order that the anchorage shall be water-tight and strain-proof, the anchored end of the cable is provided with an exterior collar 29 integral with the

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rubber sheath thereof, which collar fits into the end of the housing and is held under compression between a cover-plate 31 affixed to the said end and a movable pressure plate 33 within the housing. The cover-plate is provided with a central aperture through which the cable extends and it is held to the open end of the housing by a plurality of screws 35 or the like. The pressure plate 33, within the housing, also has a central aperture to accommodate the cable and it carries a plurality of bolts 37 that extend through the cable collar and coverplate to the exterior of the housing. Each bolt is provided with a castle nut 39 or the like whereby the pressure plate may be urged toward the cover-plate to cause the collar to bulge, radially into water-tight engagement with the inner wall of the housing.

The collar 29 also provides a strain-proof connection between the cable and connections therefrom to the terminals of the pre-amplifier tube within the housing.

As previously mentioned, if the device is to operate efficiently at ultrasonic frequencies, all dimensions of the head must be small, so small in fact that it is substantially impossible to secure a water-tight connection between the flexible diaphragms 15 and the frame 13 of the crystal unit housing through the utilization of screws, sealing gaskets and analogous devices. Also, because of the fact that Rochelle salt crystal sections are sensitive to heat, soldering of the diaphragms to the rim cannot be resorted to. According to this invention, therefore, the diaphragms 15 are first cemented to the opposite faces of the housing frame and in contact, respectively, with the faces of the piezoelectric crystal unit 11 in which terminate the ends of a compressional axis thereof. A suitable material for the diaphragms is thin phosphor bronze. Graphite is next rubbed into the joints between the diaphragms and the frame and the assembly is copper-plated to a thickness of approximately two thousandths of an inch. After the first plating operation, the head is tested for leaks and, if the joints are all water-tight, the central portion of each diaphragm is masked off by affixing a disc (not shown) of insulating material thereto and the assembly is again electroplated to an additional thickness of approximately eight hundredths of an inch.

In Figure 3 the successive plating operations are indicated by separate layers designated 41, 43 and 45 for purposes of explanation; it is to be understood, of course, that in reality the layers coalesce to form a homogeneous unbroken coating substantially integral with the surface of the diaphragms. Three coatings or layers 41, 43, and 45 have been shown because usually in the process the operator stops the plating before all of the required thickness has been deposited, and grinds away a small amount of the deposited surface. In this manner any small pits or holes can be readily detected, and corrected by grinding away the material around them. If the microphone housing is satisfactory the plating process is then continued. It is to be understood, however, that the scope of the invention includes both single and multilayer deposition of plating material. Although illustrated as a single solid element in Figures 1 and 3, the crystal unit preferably employed is of the multi-layer type described hereinafter.

The improved crystal unit, shown in Figures 6 and 7 is constituted by a plurality of sections 47, 49 and 51 having a common compressional axis and a common electrical axis. As indicated

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by the electrode connections shown in Figure 11, however, the central section 49 has been rotated 180° around the compressional axis, with respect to the other two sections, whereby potentials of like sign appear at the faces in contact with each other when the unit is stressed along its compressional axis. The sections, therefore, may be connected electrically in parallel aiding relation, as shown, with the result that the capacitance of the unit is much higher than that of a solid section having the same over-all dimensions.

Theoretically, a single pressure responsive Rochelle salt crystal element may be divided into any number of sections that are re-assembled, as shown in the drawing, electrically in parallel, and cemented together to form a composite unit. Because of the fragility of the material, however, it is not feasible to make the sections extremely thin and a three-section unit has been chosen as a practical embodiment of the invention, for purpose of explanation.

Previous to this invention, a great deal of difficulty was experienced in providing a suitable connection between the thin foil electrodes of a small crystal unit and the relatively stiff leads leading to the input terminals of the pre-amplifier tube. The difficulty, in large measure, has been obviated by the use of relatively rigid terminal plates 53 and 55 that are first soldered to the ends, respectively, of the input conductors 7 and 9, to which plates the foil leads 57 and 59 from the crystal unit are sweated. Each foil lead, thereafter, is doubled back upon itself, as shown in Figures 6 and 7, and the terminal plates are held firmly in position against the crystal unit by a wrapping 61 of thread or the like. The fragile foil leads themselves, therefore, are protected from mechanical strain and the useful life of the unit is materially increased.

It also falls within the scope of this invention to preform the microphone head 3 separately from the stem 17, by electrolytically depositing a metallic shell entirely around a piezoelectric pressure-responsive unit and, simultaneously, around a portion of the leads attached thereto.

One method, referring to Figure 8, comprises first affixing a plurality of strips 63 of cork or similar material to the sides of the crystal unit 11 after which the assembly and the leads (not shown) extending therefrom are dipped in a water-proofing material, such as shellac or the like, to provide a coating 65 that is impervious to copper sulphate solution, and the coating 65 is rendered electrically conductive by brushing-in finely divided graphite. By means of a plating operation analogous to that described in connection with Figures 1 and 3, the water-proofed unit and a portion of the insulated leads extending therefrom are entirely covered with a dense, impervious copper shell 67 that is substantially in contact with the ends of the crystal unit that are unprotected by the cork strips. The microphone head thus formed, after testing, may be affixed to the open end of a hollow stem 17 by a similar electroplating operation, or it may be utilized in any other desired manner.

As exemplified by Figure 9 (from which the leads also have been omitted), instead of forming the diaphragms by electroplating, separate diaphragms 15 may first be affixed to the ends of the crystal unit 11 by cement and the assembly, thereafter, may be entirely enclosed in an electro-deposited metallic shell 67. In that event, the waterproofing layer 65 need not extend entirely over the diaphragms provided, however,

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that the cork strips 63 and the junctions between the strips and the diaphragms are thoroughly waterproofed.

As exemplified by Figure 10, a metallic frame 69 may be substituted for the cork strips illustrated in Figures 8 and 9, and separate diaphragms may be applied thereto as described in connection with Figure 9 or the diaphragms may be constituted by opposite integral portions of the electrodeposited housing 67 as described in connection with Figure 8. The leads, also, have been omitted from Figure 10, but it is to be understood that in each of the described alternative embodiments the plating on the leads may extend outward from the shell 67, for a distance approximately indicated by the dotted arrow in Figure 2, and is integral with the housing.

From the foregoing description of a number of embodiments of this invention it should be apparent that it marks an important step forward in the construction of piezoelectric transducers intended for underwater use, or for use in other media, against contact with which the crystal unit itself must be protected. By forming the diaphragms electrolytically or by affixing them to the housing electrolytically instead of utilizing clamping rings or the like, the production of extremely small microphones is made possible, the lower limit in size being determined solely by the practicability of manufacturing the minute piezoelectric units themselves.

Other advantages of the invention will be apparent to those skilled in the art, as well as further modifications thereof. The invention, therefore, is not to be limited except insofar as is necessitated by the prior art and by the spirit of the appended claims.

I claim as my invention:

1. In a piezoelectric crystal device, a housing having an opening, a flexible diaphragm closing said opening and supported by the walls of the housing surrounding the opening and having a vibration radiating outer surface, a metallic coating integral with said housing and a portion of which is integral with said outer surface of the diaphragm.

2. As an article of manufacture, a piezoelectric crystal element having a face perpendicular to a compressional axis thereof and a metallic diaphragm electrolytically deposited on said face and substantially coextensive therewith.

3. A composite pressure responsive piezoelectric device having a compressional axis and an electrical axis, the said device comprising a stack of piezoelectric crystal sections each having the same orientation with respect to the crystallographic axes of the piezoelectric crystalline material and corresponding faces of which sections are perpendicular to said electrical axis and the opposite ends of which faces terminate in parallel planes substantially perpendicular to said compressional axis, an inner electrode interposed between each crystal section and the section contiguous thereto, an outer electrode on the top of the stack, an outer electrode on the bottom of the stack, and connections between inner and outer electrodes such that the sections function electrically in parallel aiding relation each to the other in response to stresses applied along the compressional axis.

4. The method of connecting a fragile foil lead from a piezoelectric unit to a relatively stiff conductor, that comprises joining an end of the conductor to a metallic plate having greater stiffness than the foil lead, joining the free end of the

lead to the plate, folding the lead upon itself between the plate and a face of the unit and fixing the plate firmly in position against the folded foil lead by applying substantially permanent tension thereto with respect to a face of the unit opposite to the face thereof against which the lead is folded.

5. As an article of manufacture, a piezoelectric unit having an electrode affixed to a face thereof, a foil lead extending from said electrode, a metallic plate having greater stiffness than the foil lead, the free end of the lead and the plate being conductively connected together, a conductor affixed to the plate, the foil lead intermediate the plate and the unit being reversely crimped upon itself, and means for holding the plate under pressure against the folded lead whereby the conductor is precluded from exerting any strain upon the junction of the lead with the electrode.

6. The method of increasing the electrical capacitance of a piezoelectric crystal element of the type normally provided with a pair of oppositely disposed electrodes on the surfaces, respectively, in which terminate the electrical axis of the element, without materially altering the physical dimensions thereof, that comprises sectionalizing the element along a plurality of parallel planes angularly disposed to the electrical axis, thereafter so reassembling the sections into a stack that all sections have the same orientation with respect to the crystallographic axes of the crystalline material and that the faces thereof in contact with each other will develop potentials of like sign when the composite element is subjected to pressure along a compressional axis common to all of the sections, providing the reassembled sections with intermediate electrodes and with surface electrodes and connecting said electrodes electrically in parallel aiding relation.

7. The method of providing a water-proof housing for a piezoelectric crystal element having a compressional axis the opposite ends of which axis, respectively, terminate in crystal faces which are substantially perpendicular thereto, that comprises applying vibration isolating material to portions of the element other than said faces, applying a water resistant coating to the assembly and thereafter electrolytically forming a continuous metallic jacket over the isolating material and the faces of the element.

8. A housing for a transducer having leads, comprising, a frame having a lead opening for said transducer and two open ends, a hollow stem connected to said frame at said lead opening, two flexible diaphragms carried by said frame one at each of said open ends for closing said open ends, and a metallic coating on and integral with said frame, said diaphragms, and said stem for rendering said housing waterproof.

9. The method of providing a waterproof housing for a piezoelectric crystal element having a compressional axis the opposite ends of which terminate in crystal faces which are substantially perpendicular thereto, that comprises, providing a first metallic diaphragm, connecting said first diaphragm to one of said terminal crystal faces, connecting said first diaphragm to a housing frame with the crystal element inside the frame, providing a second metallic diaphragm, connecting said second metallic diaphragm to said frame and to said other terminal crystal face; said frame and said two diaphragms establishing substantially an enclosure, and thereafter electrolytically forming a continuous metallic jacket over the frame and the said two diaphragms.

10. As an article of manufacture, a piezoelectric crystal element having an electrical axis and at least one pressure face parallel thereto, electrode means connected to at least one face of said piezoelectric crystal element which is perpendicular to said electrical axis and adapted to be connected into an electrical circuit, and a layer of electrolytically deposited metal connected to at least one pressure face of said crystal element, said element face to which said electrode is connected being substantially perpendicular to said at least one pressure face to which said layer of electrolytically deposited metal is connected.

11. In a transducer, a housing having an opening, a diaphragm having an inner and an outer major face portion, said diaphragm closing said opening and supported by the walls of the housing surrounding the opening, piezoelectric crystal element means mounted within said housing in driving engagement with the inner major face portion of said diaphragm, and a metallic coating integral with said housing and integral with and substantially covering the outer major face portion of said diaphragm.

12. In a transducer, a housing having an opening, vibration transmitting means in engagement with said housing and positioned over said opening, piezoelectric crystal element means mounted within said housing and in vibration transmitting relationship with said vibration transmitting means, and a metallic coating integral with both said housing and said vibration transmitting means for connecting said vibration transmitting means to said housing and for sealing the joint therebetween.

13. As an article of manufacture, a piezoelectric crystal element having a face perpendicular to a compressional axis thereof, vibration absorbing means in intimate contact with the faces of said piezoelectric crystal element other than said face perpendicular to said compressional axis, and a metallic coating electrolytically deposited on said crystal face and on said vibration absorbing means, said metallic coating serving as a moisture resistant housing for said piezoelectric crystal element and the portion of said coating on said crystal face serving as a diaphragm.

14. The method of connecting a fragile foil lead from a piezoelectric unit to a relatively stiff conductor, that comprises connecting an end of the conductor to a metallic plate having greater stiffness than the foil lead, connecting the free end of the lead to the plate, folding the lead upon itself between the plate and a face of the unit and firmly connecting the plate to the unit.

15. In a transducer; a housing having an opening, a cover portion for said opening, said cover portion being in engagement with said housing and together forming an enclosure, piezoelectric crystal element means mounted within said enclosed housing and being in vibration transmitting relationship with a portion of said housing, and a metallic coating on and integral with said housing and said cover for connecting said cover to said housing and for sealing the joint therebetween.

16. The method of closing an opening in a housing containing a piezoelectric crystal element which comprises the steps of: placing a diaphragm over said opening in said housing and in vibration transmitting relationship with the said crystal element, temporarily sealing the joint between said housing and said diaphragm against the ingress of liquid, electrolytically depositing a thin layer of metal on said housing and said

diaphragm to permanently seal said joint, and electrolytically building up said layer of metal to a greater thickness, the thickness of said layer at the central portion of said diaphragm being less than at the edge portion thereof.

17. The method as set forth in claim 16, further characterized in this: that the central portion of said diaphragm is masked off during the step of building up the thickness of the electrolytically deposited metal layer.

18. As an article of manufacture, a piezoelectric crystal unit having two electrodes each affixed respectively to one of two oppositely disposed crystal faces, a foil lead extending from each of said two electrodes, a metallic plate having greater stiffness than the foil lead connected to the free end of each of said foil leads, a conductor connected to each of said plates, each foil lead intermediate each plate and the unit being reversely folded upon itself, and binding means wound around the unit and each of said two plates for holding the two plates toward each

other and toward said unit whereby the conductors are precluded from exerting any tensional strain upon the junctions of the leads with the electrodes.

19. In a transducer; a housing comprising a frame having a lead opening and two open ends, a hollow stem connected to said frame at said lead opening, two flexible diaphragms carried by said frame one at each of said open ends for closing said open ends and each having an inner and an outer major face portion, piezoelectric crystal element means of the expander type mounted within said housing with a compressional axis thereof extending between said two diaphragms and with a face in driving engagement with the inner major face portion of each of said diaphragms, and a metallic coating on and integral with said frame, said stem, and the outer major face portions of said two diaphragms for rendering said housing and the joint between the said frame and the hollow stem water-proof.

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