Dec. 16, 1941. J. H. REAM 2,266,333

PIEZOELECTRIC UNIT AND METHOD OF MAKING SAME

Filed July 8, 1940

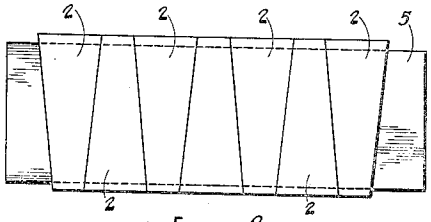


Fig. 2.

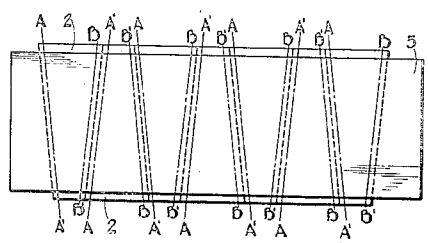


Fig. 3.

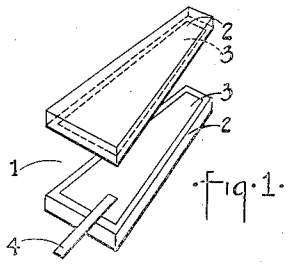


Fig. 1.

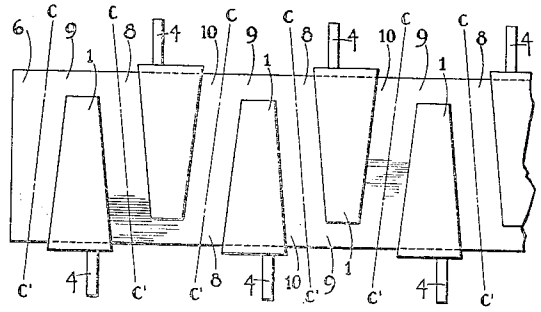


Fig. 4.

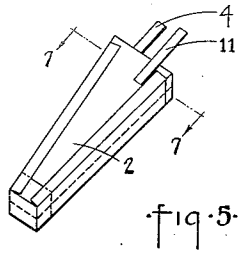


Fig. 5.

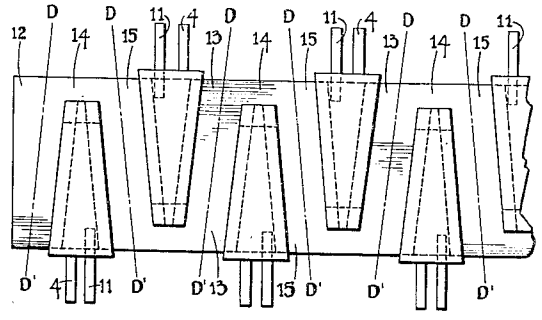


Fig. 6.

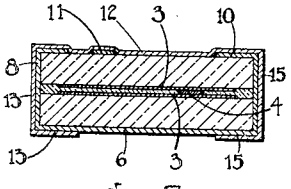


Fig. 7.

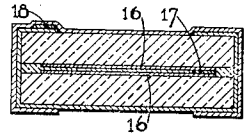


Fig. 9.

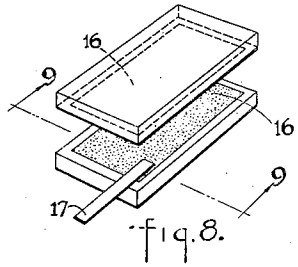


Fig. 8.

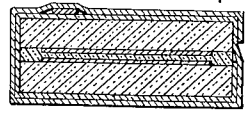


Fig. 10.

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UNITED STATES PATENT OFFICE

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PIEZOELECTRIC UNIT AND METHOD OF MAKING SAME

John H. Ream, Cleveland, Ohio, assignor to The Brush Development Company, Cleveland, Ohio, a corporation of Ohio

Application July 8, 1940, Serial No. 344,325

19 Claims. (Cl. 171—327)

This invention relates in general to multiple-plate piezoelectric crystal units and to an improved method for electroding such multiple-plate units.

It is an object of this invention to provide a piezoelectric unit that may be made in relatively large quantities at low individual cost and with uniform individual characteristics.

It is another object to provide a simplified method for making such piezoelectric units in large quantities at low individual cost.

Another object of the invention is to provide a process for making at low cost multiple-plate piezoelectric units of Rochelle salt which utilize two different kinds of electrodes.

Another object of the invention is to provide a simplified process for applying to a piezoelectric unit outer electrodes which aid in moisture-proofing the unit.

Another object is to provide a multiple-plate piezoelectric unit having a metallic sheath or jacket secured to and covering substantially the entire outer surface of the unit.

One of the principal difficulties involved in the manufacture of multiple-plate Rochelle salt units for use in various types of piezoelectric devices is that of producing piezoelectric units which can be made in large quantities at low cost. Another difficulty is to provide units of this kind which have uniform individual characteristics. The individual characteristics of units made by some of the methods of the prior art have been found to be non-uniform, this condition being apparently the result of slight variations in the intimacy of contact between the electrodes and the crystalline piezoelectric material, these slight variations causing rather large variations in the capacitance of the units.

Electrodes have been applied to Rochelle salt crystal assemblies by two methods which have been used extensively in commercial production. One method, which is described in the U. S. Patent No. 1,995,257, granted to C. B. Sawyer, consists of cementing electrodes of metal foil to the crystal by means of an adhesive that has the property of contracting upon drying, and rubbing the foil into intimate contact with the crystal before the adhesive has dried appreciably. While being a thoroughly commercial process, it is unduly expensive because as heretofore practiced, it involved many time-consuming operations. The other method, which is described fully in U. S. Patent No. 2,106,143, granted to A. L. W. Williams, consists of spraying the crystal with a thin coating of finely divided conducting material such as colloidal graphite, the material being applied in the wet state. Crystal units having graphite electrodes have a higher capacitance than similar units provided with foil electrodes because of the more intimate electrode contact. Units provided with such electrodes also manifest greater uniformity in their capacitance and sensitivity when produced in large quantities at commercial rates of production. This is due in part to the fact that by using a mask during the spraying operation it is possible to control the size of the electrodes with greater accuracy. However, the method has its disadvantages, one of which lies in the fact that in order to attach connecting leads to the outer or remote electrodes and to increase the conductivity of the electrodes, a layer of metal foil needs to be cemented in contact with the sprayed electrode. This involves one or more additional operations in the process and consequently adds to the individual cost of manufacture. In addition, units provided with the graphite electrodes exhibit a greater variation in sensitivity and capacitance with temperature changes than do similar units provided with foil electrodes, and hence such units may be objectionable for some uses.

It has been found that by modifying the first method in a novel manner, a simplified and improved method is obtained which involves fewer time-consuming operations and thereby permits material reductions in manufacturing cost. Briefly, the new method is characterized by the use of outer foil electrodes which are wrapped about the piezoelectric assembly in such manner as to overlap a suitably disposed electrode extension, thereby effectively securing the extension in good mechanical and electrical engagement with the assembly and with the foil sheath or jacket which is formed by the electrode wrapping. It is through the use of this characterizing feature that the foregoing objects are achieved.

The invention and its modifications will be understood more fully through reference to the drawing, and to the following detailed description.

In the drawing:

Fig. 1 is an enlarged and exploded perspective view of a 2-ply bimorph assembly ready to be electroded in accordance with the invention.

Figs. 2 and 3 are plan views illustrating preferred method steps by which a foil electrode may be applied to the inner face of each piezoelectric crystal plate of the type used in the bimorph assembly of Fig. 1.

Fig. 4 is a plan view illustrating the preferred

method step by which one outer foil electrode is applied in accordance with this invention to a bimorph assembly of the type shown in Fig. 1.

Fig. 5 is an enlarged perspective view of a partially electroded bimorph assembly showing the electrode which has been applied thereto by the method step of Fig. 4 and showing an electrode extension disposed in position on the surface of the assembly in preparation for the following method step.

Fig. 6 is a plan view illustrating the preferred method step by which a second outer electrode of metal foil is applied to the unelectroded face of the partially electroded bimorph assembly shown in Fig. 5.

Fig. 7 is an enlarged sectional view of the completed bimorph unit which has been made by the process illustrated by Figs. 1 through 6, the section being taken at a position corresponding approximately to that indicated by line 7, 7 of Fig. 5.

Fig. 8 is an exploded perspective view of a bimorph assembly having inner electrodes of sprayed graphite, and ready to have outer electrodes applied in accordance with the method of this invention.

Fig. 9 is an enlarged sectional view of the completed bimorph unit of Fig. 8 after it has been electroded externally in accordance with the invention, the section being taken approximately at the position indicated by line 9, 9 of Fig. 8.

Fig. 10 is an enlarged sectional view of a modified form of the invention and illustrates a piezoelectric unit having a sheath electrode formed from a single length of foil.

Referring now to Fig. 1 which shows the construction of a simple 2-ply assembly ready to be electroded in accordance with this invention, it will be seen that the assembly 1 contains plates 2, 2 of crystalline piezoelectric material which have electrodes 3, 3 composed of metallic foil, such as tin foil, secured to their inner faces. The plates are secured together in any suitable manner as by means of cement and are provided with a lead or electrode extension 4 positioned between their inner faces in electrical engagement with the inner electrodes. In an assembly as thus described, the electrodes 3, 3 should be spaced inwardly from all of the edges of the face to which each is applied so as to provide a moderate margin all around. It will be understood from the subsequent description that a margin is needed to prevent electrical leakage between the inner and outer electrodes.

In making a unit of the kind shown in Fig. 1, the individual piezoelectric plates 2, 2 are first electroded in any suitable manner. When foil electrodes are to be applied, a procedure such as that illustrated by Figs. 2 and 3 is preferred. In this process, a strip of foil 5 having one surface coated with a suitable adhesive is stretched out upon a flat surface and individual plates of piezoelectric material are then applied one by one or in groups to the adhesively coated face. While the strip of foil may be wider than the unit, preferably it is cut to a predetermined width, such that when the individual plates are applied to it, substantially in the relation shown, equal margins will be formed adjacent the top and bottom edges. When the plates are trapezoidal in shape, they preferably are applied in the alternate arrangement shown in the figure, so as to facilitate subsequent handling. After a suitable number of such plates has been applied to the adhesive face of the strip of foil, the plates and the adhering foil are turned over so that the foil is uppermost as shown in Fig. 3. The foil is next rubbed into intimate contact with each plate, after which each plate is trimmed by cutting through the foil substantially on the dot-and-dash lines A—A', B—B'. The excess foil is then peeled off, leaving margins adjacent the trimmed edges of each plate. In this way, a foil electrode may be applied to a face of a plate by a process involving a minimum number of operations. After the inner electrode has been applied, a pair of the semi-electroded plates, having proper mutual piezoelectric orientation when placed together with their electroded faces in contact, are selected. An electrode extension 4 is preferably applied to the electroded face of one of the selected plates, the extension being applied thereto in such manner as to make electrical contact with the electrode. Suitable cement may then be applied to either or both of the electroded faces of the selected plates, after which the plates are juxtaposed and firmly pressed together for the purpose of bringing the electrodes 3, 3 into contact with the lead extension 4 and for the further purpose of pressing any excess cement out from between the two plates. A 2-ply assembly which is ready to be electroded in accordance with the invention is thereby produced.

The first step of the novel electroding process of the invention is illustrated by Fig. 4. In performing this step of the process, a strip of foil 6 having suitable adhesive applied to one face thereof is stretched out upon a flat surface with the adhesive face uppermost. Two-ply assemblies, such as the one shown in Fig. 1, are then placed upon the foil strip, being positioned thereon preferably so as to leave a margin adjacent to the edge of the assembly from which electrode extension 4 projects. When the assemblies are applied to the foil, they should also be spaced apart an appropriate distance for a purpose which will be understood from the subsequent description. After a suitable number have been so applied, the foil is cut substantially on the lines C—C', C—C', thus freeing each assembly from the others. It will be noted that by cutting the foil on these lines, wide borders 8, 9, 10 of foil remain adjacent three edges of each assembly. The next step in the process consists in folding the borders preferably in the order 9, 8, 10, and wrapping them about the sides of the assembly and onto the opposite face, as shown in Fig. 5.

After one outer electrode has been applied in the manner last described and its border portions have been folded about the edges to overlap on to the opposite face, an electrode extension 11 is then applied to the outer surface of the assembly as thus partially electroded, the extension preferably being disposed in contact with one of the border portions. It may be held in place temporarily by a small amount of adhesive. Fig. 5 shows the partially electroded assembly having a lead extension in position on an exposed crystalline face of the assembly. The partially electroded assembly as thus produced is then ready for the final step in the electroding process.

The final step is illustrated by Fig. 6. It will be apparent at the outset that this step of the process is substantially a repetition of the step illustrated by Fig. 4 except that an assembly such as the one shown in Fig. 5 is here involved. In this step, the partially electrodes assemblies are applied to a strip 12 of adhesively coated foil, being placed thereon with the previously electrod-

ed face of the unit uppermost and with the unelectroded face which carries electrode extension 11, in contact with the adhesive layer of the electrode strip. A convenient number of such assemblies is applied to the strip after which the electroding strip is cut substantially on the lines D—D', D—D' so as to separate the assemblies from each other. Again the border portions 13, 14 and 15 of the foil strip are folded about the edges of the assembly and on to the opposite exterior face of the unit, thereby completing the step. It will be noted that by reason of the fact that the two outer electrodes applied by the foregoing process steps mutually overlap on three edges of the unit, a sheath or jacket of metal foil is formed which is secured to substantially the entire exposed surface of the assembly. This metal sheath, being relatively impervious to moisture, aids in preventing deterioration of the unit as well as providing the necessary electrodes. In addition the sheath facilitates the subsequent application of a smooth coating of suitable moisture-proofing material such as shellac.

The nature of this moisture-proofing sheath will be more apparent from the sectional view shown in Fig. 7. It will be seen that each of the exterior faces of the piezoelectric plates is in contact over substantially its whole area with the electrically conductive metal foil. Moreover, it will be observed that each of the enclosed edges of the unit is protected by means of a double layer of foil. The double layer on the edges and corners protects the parts of the unit which are most easily injured, and also permits a more uniform coating of moisture-proofing material to be applied to the parts when such protective material is used. The metal sheath is particularly beneficial when the units are moisture-proofed by being dipped into materials such as shellac, or the polymerized vinyl chloride compositions known as Korolac, since it provides a smooth metallic base to which a smooth, uniform layer of such materials will adhere tenaciously. It will be understood that the electrodes and lead extensions shown in Fig. 7 are greatly exaggerated in thickness.

It will be noted that these various advantages have been obtained through the use of a process which involves a minimum number of operations. By reason of this latter fact, the individual cost of the units is materially reduced as compared with the cost of units made by prior methods. In addition, since only the interior electrodes of the assemblies are trimmed, less variation occurs in the electroded areas of the various units than occurs in units in which both the inner and outer electrodes are trimmed. Hence, the capacitance of units made by this process is more uniform. This latter advantage may be utilized even more effectively by substituting sprayed graphite electrodes or electrodes composed of similar finely conductive material for the inner foil electrodes 3, 3 since when such sprayed electrodes are applied to the units by means of masks, the variation in electroded area is reduced to a minimum. Such units also possess additional advantages which will be discussed more fully below.

Fig. 8 illustrates a 2-ply piezoelectric assembly which has inner electrodes 16, 16 composed of sprayed colloidal graphite with a foil electrode extension 17 in electrical contact therewith. The method by which such multiple assemblies may be made is fully disclosed in Williams Patent No. 2,106,143. Such an assembly may be electroded externally with foil electrodes applied in accordance with this invention by following the steps described above and illustrated by Figs. 4, 5 and 6. In accordance with a preferred modification of the method, the outer electrode extension 18 is disposed in contact with one of the folded border portions of the outer foil electrode first applied to the assembly. The unit produced by the process and embodying this latter modification, has a structure like that shown in section in Fig. 9.

As indicated above, units having inner electrodes of graphite or similar finely-divided conductive material, and outer foil electrodes applied in accordance with this invention to form an enclosing sheath, have additional advantages which enhance their utility as compared with similar units having inner electrodes of foil. Such units accordingly are a preferred form of the invention. The advantages here referred to include a higher degree of uniformity in capacitance, greater capacitance, and lower individual cost. In addition, such units are an improvement upon the all-graphite units of the above mentioned Williams Patent since they are cheaper to make and exhibit somewhat less variation in sensitivity and capacitance with temperature. As previously pointed out, this latter variation in the all-graphite units may be quite objectionable under some conditions of use, but since the variation may be materially reduced by substituting the outer sheath electrodes of this invention for the outer graphite electrodes of the Williams units, the objectionable feature is somewhat mitigated.

It will be observed that when assemblies are electroded in accordance with the method of this invention, the lead extension is preferably disposed between two overlapped portions of foil. As previously pointed out, this disposition insures good electrical contact between the extension and the sheet electrode, and in addition, results in a strong mechanical joint. While the extension may be disposed elsewhere in accordance with the invention, as for example in direct contact with the piezoelectric material, its placement between the laminations of the lapped joint is somewhat advantageous especially when roughened leads such as shown and described in Williams Patent No. 2,106,143 are used or when the leads are of moderately heavy gauge material. It will be appreciated that under these conditions, it is likely to be more difficult to rub the lead into intimate and direct contact with the piezoelectric crystalline material, with the consequent result that small areas of the latter material will not be effectively electroded. This condition is avoided, as will be apparent, when foil electrode material is placed between the lead and the piezoelectric material.

The advantages of units made in accordance with this invention, insofar as cost is concerned, will be understood more fully by comparing the steps involved in the method of this invention with the steps involved in making a similar unit by the process described in Williams Patent No. 2,106,143 and by the process described in Sawyer Patent No. 1,995,257. For the purpose of facilitating this comparison the principal steps involved in making a 2-ply unit in accordance with the process of the latter patent, wherein all electrodes applied to the plates are composed of metallic foil, are here outlined:

1. Provide two crystalline plates.

2. Apply adhesive-coated foil to one face of each plate leaving margins adjacent the end edges.
3. Trim the two side edges of the foil to complete a margin surrounding the electrode.
4. Apply cement to an electroded face of one plate.
5. Bring electroded faces of the two plates together with an electrode extension between and squeeze plates together to exude excess cement.
6. Apply adhesive-coated foil to exterior faces of assembly.
7. Position electrode extension in contact with one or both exterior foil electrodes.
8. Apply adhesive-coated foil patch over each electrode extension to hold the extension in place.
9. Trim marginal edges of exterior electrodes and the patches affixed thereto.

In making a 2-ply bimorph in accordance with the method disclosed in Williams Patent No. 2,106,143, the principal steps would be substantially as follows:

(Note: Each step of this method which corresponds with a similar step in the above list bears the same numeral.)

1. Provide two crystalline plates.
2. Spray colloidal graphite on one face of each plate using a mask.
4. Apply cement to a graphited face of one plate.
5. Bring graphited faces of both plates together with electrode extension between them and squeeze the plates together to exude excess cement.
6. Spray colloidal graphite on the remote faces faces using a mask.
7. Position lead or leads in contact with one or both graphite electrodes.
8. Apply adhesive-coated foil patch over each lead.
9. Trim margins of patches to correspond with margins of outer graphite electrodes.

A bimorph made by this method will have the general appearance of the unit shown in Figs. 12 or 13 of the Williams patent.

In making a 2-ply bimorph in accordance with the most preferred form of the invention disclosed herein, the principal steps would be substantially as follows:

1. Provide two crystalline plates.
2. Apply electrode of finely divided conductive material to one face of each plate using mask (by spraying, sputtering or otherwise).
4. Apply cement to electroded face of one plate.
5. Bring electroded faces of both plates together with electrode extension between and squeeze the plates together to exude excess cement.
6. Apply adhesive-coated foil to one exterior face of the assembly cutting the foil, if necessary, to provide a margin on the lead edge and to provide projecting borders on the remaining edges.
   A. Fold borders about the assembly in the manner described in connection with Figs. 4 and 5.
7. Apply adhesive-coated lead to border portion of the electrode.
   B. Repeat steps 6 and A on the opposite exterior face of the assembly.

In comparing these three methods, it will be seen that the method of this invention avoids steps 3 and 9 of the Sawyer process and avoids step 9 of the Williams process. As will be noted, these are the trimming steps of each process. Herein lies the particular feature of the method of this invention insofar as cost reduction is concerned, since these trimming steps acoount for at least 8 individual operations in the Sawyer process and 6 in the Williams process, each of which requires special care and skill and is time-consuming. It will be observed that steps A and B of the method of this invention replace the trimming steps and substitute steps therefor which may be performed quickly and easily and with a minimum of care consistent with quality. The expensive steps of the prior methods are thereby replaced with steps which permit a higher rate of production with a consequent reduction in the individual cost of the units.

The invention has been explained through reference to certain specific forms which should be considered as illustrative in character rather than limiting, since various modifications may be made. For example, while the invention has been described in connection with two-ply assemblies, it will be obvious that assemblies composed of more than two individual piezoelectric plates may be electroded externally in the same manner. It will also be understood that while the preferred form of the external electrode consists of two sheets of foil joined together in side by side relationship to form the encircling electrode previously described, such an encircling electrode may be made from a single length of foil as shown in Fig. 10, or from a plurality of lengths, opposed margins of which are overlapped and joined together to form a lapped joint. A further embodiment of the invention may consist of a piezoelectric unit which includes an encircling jacket or sheath electrode with or without an electrode extension secured to it between the overlapping laminations of a lapped joint in the electrode, and such jacket or sheath electrode may function as the sole external electrode, or it may be used in conjunction with auxiliary outer electrodes such as electrodes composed of colloidal graphite. In such a unit, the foil jacket functions to protect the unit from moisture and damage as described above, and retains its advantages over similar protective jackets which are more difficult and therefore more expensive to apply. Numerous other modifications may be made and will be apparent to those skilled in the art. Accordingly the scope of the invention should be determined from the following claims taken in conjunction with the foregoing description and explanation.

What I claim is:

1. As an article of manufacture, an operative multiple-plate piezoelectric unit having a pair of remote major faces and intervening side and end faces, said unit being provided with an encircling jacket of metal foil secured to said major faces and said intervening side faces, each of the edges of the unit which underlie and engage the said jacket being covered by a lapped joint in said jacket consisting of at least two layers of overlapping metal foil.

2. As an article of manufacture, an operative multiple-plate piezoelectric unit having a pair of remote major faces and intervening side and end faces; an encircling jacket electrode of metal foil composed of two quadrilateral sections of foil joined together in side by side relationship, the first of said sections covering and being secured in intimate relationship to substantially all

of a first of said major surfaces and extending onto adjacent side faces of the unit and onto at least a part of the second major face, the second of said sections covering and being secured in intimate relationship to substantially all of the uncovered portion of the second major face, and to at least the opposed marginal portions of the first section of foil to form lapped joints therewith.

3. An article as claimed in claim 2 wherein the said second section overlaps the said opposed marginal portions of the first section of foil and its opposed margins extend onto at least a part of the opposite major face, thereby providing two layers of foil on each of the encircled edges of the unit.

4. An article as claimed in claim 2 wherein an electrode extension is disposed underneath and in immediate electrical contact with at least one of said sections of foil and wherein said electrode extension projects beyond a bounding edge of the unit.

5. As an article of manufacture, an operative multiple-plate piezoelectric unit having an outer encircling jacket electrode of metal foil, said jacket having at least one lapped joint therein and an electrode extension disposed between and secured to the overlapping portions of foil which form the said lapped joint.

6. An article of manufacture as claimed in claim 5 wherein said jacket is composed of a single section of foil, the opposed marginal portions of which form the lapped joint.

7. An article as claimed in claim 5 wherein said electrode is composed of a plurality of sections of foil which are joined together in side by side relationship, each of the joints being lapped joints.

8. An article as claimed in claim 5 wherein said piezoelectric unit is a multiple-plate unit having a pair of remote major faces and intervening side and end faces, and wherein said jacket is composed of two quadrilateral sections of metal foil joined together in side by side relationship, the first of said sections covering and being secured in intimate relationship to substantially all of one of said major surfaces and extending on to adjacent side faces of the unit and on to at least a part of the opposite major face, the second of said sections covering, and being secured in intimate relationship to, substantially all of the uncovered portion of the latter major face and to opposed marginal portions of the first of said sections of foil.

9. An article as claimed in claim 5 wherein the jacket electrode is folded about and secured to an end face of the unit, thereby forming a sheath electrode.

10. An article as claimed in claim 5 wherein electrodes applied to the inner faces of the piezoelectric plates composing the unit are composed of finely divided electrically conductive material.

11. As an article of manufacture, a multiple-plate piezoelectric unit comprising: a plurality of juxtaposed plates secured together flatwise and appropriately oriented to provide an operative assembly; an inner electrode system providing electrodes at inner faces of said plates and including an electrode extension which projects beyond a bounding face of the unit; an outer electrode system effectively insulated from the said inner system and providing electrodes for the outer faces of the outermost plates of the unit, said outer system including a sheath electrode of metal foil which is secured to said outer faces and to intervening edges of the plates of the unit and which has a lapped joint therein formed of mutually overlapped portions of metal foil which are secured to each other and to an electrode extension which is disposed between the overlapped portions of the joint and projects therefrom.

12. An article as claimed in claim 11 wherein the electrodes of said system consist of finely divided electrically conductive material.

13. An article as claimed in claim 11 wherein said sheath electrode is open at only one end.

14. An article as claimed in claim 11 wherein said sheath electrode is composed of two sections of foil secured together in side by side relationship by means of lapped joints.

15. A piezoelectric unit comprising a plurality of quadrilateral plates of crystalline piezoelectric material secured together flatwise in face to face relationship, an inner electrode system providing electrodes for the inner faces of the plates and comprising electrodes composed of finely divided electrically conductive material secured to the inner faces of each of said plates, and a pair of metallic foil electrodes secured one to each of the exterior faces of the outermost plates of the unit, said pair of metallic foil electrodes having border portions thereof folded about three contiguous edge faces of the unit in mutually overlapping relationship and secured to each other and to said edge faces to form a moisture-proofing sheath covering substantially all of said unit except one edge face thereof, an electrode extension secured in electrical engagement with an inner electrode and extending out of said unit at the said uncovered edge thereof, and an electrode extension secured to the foil electrodes between laminations of the overlapped border portions.

16. In the method of making a multiple-plate piezoelectric unit, the steps of: providing an assembly comprising a plurality of juxtaposed piezoelectric plates secured together flatwise and including an inner electrode system providing electrodes for inner faces of said juxtaposed plates, said electrode system including an electrode extension which projects from an edge of the assembly; intimately securing to substantially all of the outer face of one of the outermost plates of the assembly a sheet of metallic foil electrode material having lateral border portions which extend beyond and along opposite edges of said face and which terminate adjacent the said edge beyond which the inner electrode extension projects; folding said lateral border portions of said sheet onto the contiguous edge faces of the assembly and onto the opposite outer face of the assembly; thereafter securing a second sheet of metallic foil to the said opposite face of the assembly to overlap said folded border portions thereby forming an open ended encircling electrode.

17. In the method of making a multiple-plate piezoelectric unit, the steps of: providing an assembly comprising a plurality of juxtaposed piezoelectric plates secured together flatwise and including an inner electrode system providing electrodes for inner faces of said juxtaposed plates, said electrode system including an electrode extension which projects from an edge of the assembly; intimately securing to substantially all of the outer face of one of the outermost plates of the assembly a sheet of metallic foil electrode material having lateral border por-

tions which extend beyond and along opposite edges of said face and which terminate adjacent the said edge beyond which the inner electrode extension projects; folding said lateral border portions of said sheet onto the contiguous edge faces of the assembly and onto the opposite outer face of the assembly; affixing an outer electrode extension to the outer surface of said unit as thus partially electroded in such manner as to project beyond the same edge from which the inner electrode extension projects; thereafter securing a second sheet of metallic foil to the said opposite face of the assembly to overlap said folded border portions and the said outer electrode extension, thereby forming an open ended encircling electrode having an outer electrode extension projecting therefrom.

18. In the method of making a multiple-plate piezoelectric unit, the steps of: providing an assembly comprising a plurality of juxtaposed piezoelectric plates secured together flatwise and including an inner electrode system providing electrodes for inner surfaces of said juxtaposed plates, said electrode system including an electrode extension which projects from an edge of the assembly; intimately securing to substantially all of the outer face of one of the outermost plates of the assembly a sheet of metallic foil electrode material having lateral border portions which extend beyond and along opposite edges of said face and which terminate adjacent the said edge beyond which the inner electrode extension projects; folding said lateral border portions of said sheet onto the contiguous edge faces of the assembly and onto the opposite outer face of the assembly; affixing an outer electrode extension in contact with one of said folded border portions in such manner as to project beyond the same edge from which the inner electrode extension projects; thereafter securing a second sheet of metallic foil to the said opposite face of the assembly to overlap said folded border portions and the said outer electrode extension, thereby forming an open ended encircling electrode having an outer electrode extension projecting therefrom from between the overlapping laminations of a lapped joint therein.

19. In the method of making a multiple-plate piezoelectric unit, the steps of: providing an assembly comprising a plurality of juxtaposed piezoelectric plates secured together flatwise and including an inner electrode system providing electrodes for inner surfaces of said juxtaposed plates, said electrode system including an electrode extension which projects from an edge of the assembly; intimately securing to substantially all of the outer face of one of the outermost plates of the assembly, a sheet of metallic foil electrode material having border portions which extend beyond all of the edges of said face except the said edge beyond which the inner electrode extension projects; folding said border portions of said sheet onto the contiguous edge faces of the assembly and onto the opposite outer face of the assembly; affixing an outer electrode extension to one of said folded border portions in such manner as to project beyond the same edge from which the inner electrode extension projects; thereafter securing a second sheet of metallic foil to the said opposite face of the assembly to overlap said folded border portions and the said outer electrode extension, thereby forming an encircling electrode sheath having an electrode extension projecting therefrom from between the overlapping laminations of a lapped joint therein.

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