Nov. 6, 1945. J. P. ARNDT, JR 2,388,242

PIEZOELECTRIC TRANSDUCER

Filed Jan. 11, 1943

FIG.1

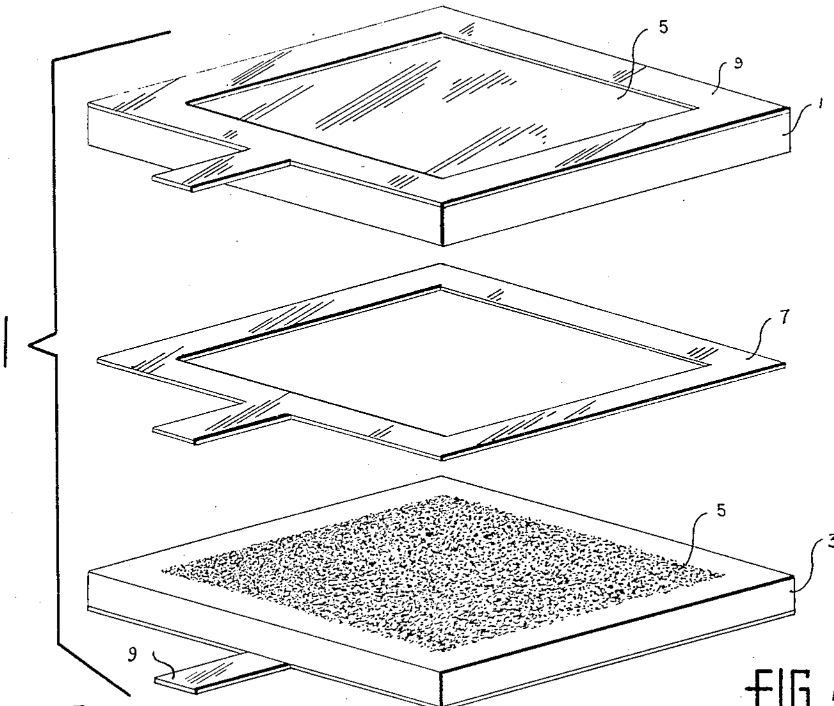
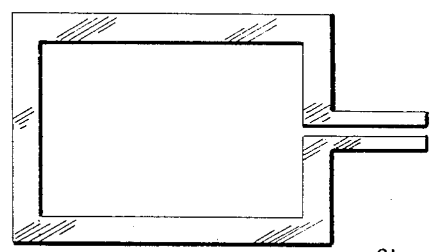


FIG.4



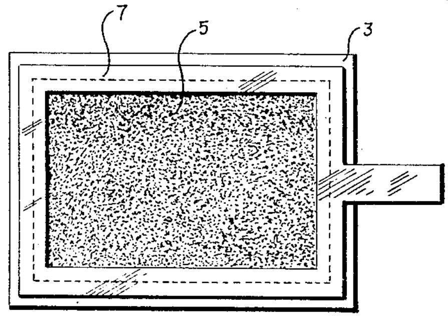
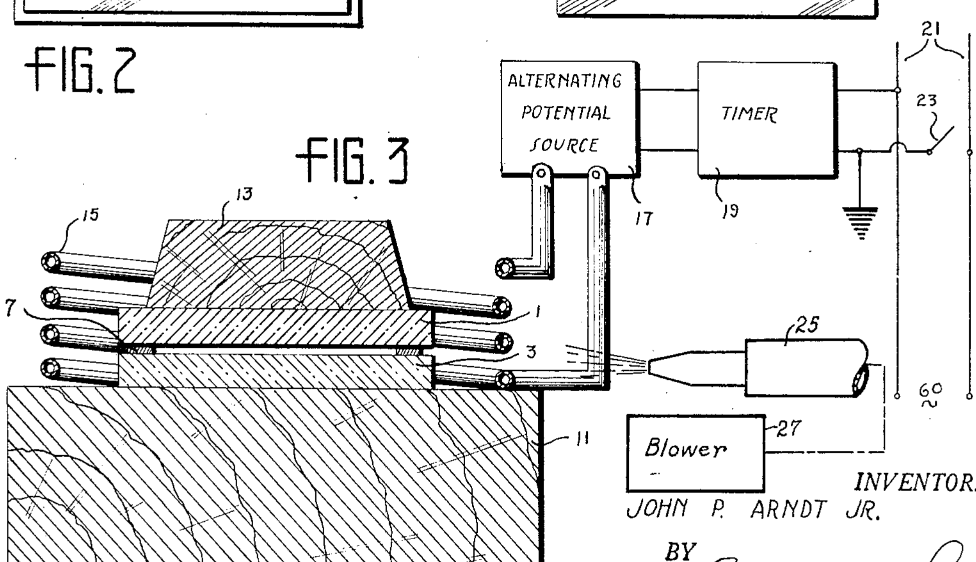


FIG.2

FIG.3



INVENTOR.
JOHN P. ARNDT JR.

BY
T. R. Goldsborough
ATTORNEY

Patented Nov. 6, 1945

2,388,242

UNITED STATES PATENT OFFICE

2,388,242

PIEZOELECTRIC TRANSDUCER

John P. Arndt, Jr., Euclid, Ohio, assignor to The Brush Development Company, Cleveland, Ohio, a corporation of Ohio

Application January 11, 1943, Serial No. 471,968

33 Claims. (Cl. 171—327)

This invention relates to piezoelectric transducers and, more particularly, to transducers of the general type constituted by a plurality of sections of crystalline piezoelectric material that are cemented to gether to form a composite element that either bends, expands or contracts, twists or otherwise deforms when subjected to electric potentials.

Previous to the invention, a number of methods had been proposed for providing the major surfaces of a crystal section with conductive electrodes and, thereafter, for joining the electroded surfaces firmly to each other to provide a multiplate assembly of the type described. One method that has achieved great commercial success is explained in the United States patent to A. L. W. Williams, No. 2,106,143, which discloses the utilization of finely divided graphite or the like as an electrode.

In accordance with the teaching of the Williams patent, a multiplate flexing element such as a "Bimorph," for example, is fabricated from two plates cut from a homogeneous Rochelle salt crystal, each of which plates carries upon its two major faces electrodes comprising colloidal graphite. The two plates bearing these coatings are cemented together with an electrode extension, formed of thin metal, clamped between them. The cementing, however, is necessarily a manual operation, inasmuch as each assembly must be handled individually, and the labor cost is out of proportion to the material cost of the crystal sections themselves.

Furthermore, considerable difficulty has been experienced in obtaining multiplate assemblies having uniform electrical and mechanical characteristics, such for example, as electrical and mechanical impedances, largely because of the fact that the thickness and uniformity of the cement layer vary for different operators and between units made by the same operator.

It is, accordingly, an object of this invention to provide an improved method of manufacturing a piezoelectric transducer of the multiplate type, whereby the number of manual operations shall be minimized and the labor cost, accordingly, diminished.

Another object is to provide a method of manufacturing multiplate piezoelectric transducers whereby a more uniform product shall be obtained.

Another object is to provide a method of the type described that may be practiced through the utilization of automatic machinery.

Another object is to provide an improved method of fabricating a piezoelectric transducer of the type described whereby an electroded crystal section may be provided with a conductive lead and simultaneously be joined to a similar electroded section without the utilization of cement.

Another object of the invention is to provide an improved piezoelectric transducer, of the type described, wherein internal losses shall be minimized and, consequently, which shall be more efficient than similar transducers of types heretofore known.

Briefly, in accordance with this invention, one face of a metal foil element having a lead extension is autogenously welded, so to speak, to the surface of a fusible piezoelectric crystal section, and in contact with the boundaries of a previously applied conductive coating of colloidal graphite or the like, by causing the said element to be heated momentarily to a temperature sufficiently high to melt a portion of the crystalline material in contact therewith. A minor portion of the electroded face of a similar section may be welded simultaneously to the other surface of the contact element, the two welds, after the assembly has cooled, serving in lieu of cement for joining the sections together in face to face relation.

Concurrently with the melting of the crystalline material in direct contact with the surface, or surfaces of the contact element, some of the material adjacent to the boundaries of the foil is also melted and intermingles to contribute to the strength of the weld.

Preferably, the metal foil is in the form of a closed loop, or narrow strip that contacts the coated faces of the sections near the edges thereof whereby the said sections are joined to each other only in a restricted region adjacent to their peripheries. Accordingly, the greater portion of each opposed surface is unrestrained and the multiplate flexing element is more efficient, when utilized as a transducer, than conventional devices of a similar type.

It is preferable to heat the contact element inductively although heating it by any other means, such as by connecting opposite portions thereof to the terminals of a source of alternating or of direct potential, lies within the spirit and scope of the invention.

It probably would be assumed, in advance, by those familiar with fusible piezoelectric material, that the sections would be damaged by heat during the joining operation. By experiment, however, it has been established that no detrimental changes occur if the heating is momentary and is just sufficient to cause fusion of a minute layer of the crystalline material. The method of the invention is justified also by the disclosure in the United States patent to Paul Pfundt, No. 2,168,943, but it goes farther than the patented procedure in that, through its practice, the electroded crystal sections not only are joined together but are simultaneously provided with a conductive lead extension.

It might also be assumed from the foregoing that the invention is limited in its application to Rochelle salt sections. That is not the case, however, inasmuch as it may be practiced in connection with substantially any fusible piezoelectric material, such as a mixed tartrate of sodium and rubidium, crystalline primary ammonium phosphate, primary sodium or potassium phosphate, isomorphous mixtures or phosphates, primary arsenates, etc., with satisfactory results.

Inasmuch as the invention relates primarily to a method of affixing a lead extension and contact member to an electroded crystal section and to the fabrication of multi-section-assemblies, no mention need be made herein to the theory underlying such devices nor to the specific orientation of the several sections with respect to the crystallographic axes of the mother crystals. Such information, should it be desired, may be found in the United States reissue patents to C. B. Sawyer, Nos. 20,213 and 20,680, as well as in many other patents well known to those skilled in the art.

The novel features considered 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 best be understood from the following description of certain specific embodiments, when read in connection with the accompanying drawing, in which:

Figure 1 is an exploded view, in perspective, of a multiplate piezoelectric transducer constructed according to the invention;

Figure 2 is a plan view of a piezoelectric crystal section provided with a conductive lead extension according to the invention;

Figure 3 is a view, partly in vertical section and partly diagrammatic, exemplifying a step in the improved method of fabricating a multiplate flexing element, and

Figure 4 is a plan view of a lead extension of alternative type.

In all figures of the drawing, equivalent elements are similarly designated.

Referring now to Figures 1 and 2 of the drawing, a multiplate transducer constructed according to the invention comprises two rectangular sections of piezoelectric material which, for purposes of convenience will be referred to, respectively, as an upper section, 1, and a lower section, 3. The sections may be cut from a mother crystal of Rochelle salt and oriented with respect to the crystallographic axes as shown in the Sawyer reissued patents, to provide either a "bender" or a "twister" element, or may be oriented to provide a multilayer element of the expander type.

Each section has two parallel major faces resulting, for example, from a machining operation such as is disclosed in the United States Patent to C. B. Sawyer et al., No. 2,112,636, and each major face has been provided with a conductive coating 5 of a material such as colloidal graphite. The method disclosed in the Williams patent may be employed for applying the colloidal graphite coating, or the coating may be metallic in character and may be applied thermionically, by the Shoop spray process, or by any other method which insures conductive contact with the surfaces of the sections.

An intermediate lead extension 7 is provided, which makes contact with the conductive layer on the bottom major face of the upper section and the layer on the top major face of the lower section. The lead extension is in the form of a closed loop of metal foil or the like, the outside dimensions of which, in the plane thereof, are slightly less than the outside dimensions of the opposed faces of the crystal sections, as will be clear from an inspection of the face of the lower section shown in Figure 2. The inside dimensions of the loop are somewhat less than those of the graphite electrode, thus providing an overlap for contact purposes. The conductive layer also stops short of the edges of the sections whereby the finished device may be wrapped with foil for shielding purposes, the foil also serving to connect the outer electrodes together, without danger of making contact with the central lead extension.

The device may be provided with two outer lead extensions 9 as shown in the drawing, each extension also having the form of a closed loop which lies along the periphery of the section.

The lead extensions are preferably fabricated from metallic foil having a thickness of the order of .0005 to .015 of an inch. It is believed that silver, nickel and plated iron or steel are the most suitable electrode materials but the invention, obviously, is not limited to their use alone.

The improved method of manufacturing a multiplate piezoelectric transducer is exemplified by Figure 3 of the drawing. In practicing the method a lower section 3 of piezoelectric material, the upper surface of which carries a conductive layer of colloidal graphite or the like (not shown), is placed upon a suitable non-metallic support 11, an intermediate lead extension 7 is placed upon the upper surface of the section, an upper section 1, previously provided with a similar conductive layer (not shown), is superimposed upon the lower section and pressure is applied to the assembly as exemplified by the weight 13 shown in the drawing.

The lead extension loop is then heated, preferably by inducing alternating current therein and permitting it to flow for a time just sufficient to cause slight fusion of the section-faces in contact therewith and immediately adjacent thereto. For that purpose, an encircling coil 15 of copper tubing or strap may be employed, which coil is supplied with alternating potential from an appropriate source 17 such as an oscillator-power amplifier. Means, such as a commercial time switch 19 interposed between the potential source and the power supply conductors 21, are provided for limiting the heating time to a pre-determined interval. A master switch 23 may, of course, be interposed in the supply circuit if desired.

Outer lead extensions 9 are not shown in Figure 3 but it is to be understood that they may be applied, simultaneously, to the upper and lower crystal sections if desired.

If semi-automatic fabrication is preferred, the support 11 may be replaced by a belt (not shown) that moves past a loading station, a heating station and an unloading station. At the loading station the section-assemblies, each with one or more lead extensions, are placed in spaced apart relation upon the belt which carries them through a high frequency electromagnetic field and out toward the unloading station where they are removed. The motion of the belt may be continuous or step by step, depending largely upon the dimensions of the crystal sections and the time-period necessary for heating the lead extension.

Each assembly, before being placed upon the moving belt, may be wrapped with thread, or a rubber band or other non-metallic means may be employed for holding the sections in fixed position with respect to each other during the heating operation.

It is difficult to give specific values for the current necessary for a satisfactory weld, or to state the length of time the current should flow in any given instance. These factors can be determined only by experiment, inasmuch as they depend upon the resistance of the electrode, the dimensions of the crystal sections and upon the particular piezoelectric material utilized. It is considered preferable, however, to heat the electrode only momentarily to a temperature above the melting point of the crystalline material, say 100° Centigrade in the case of Rochelle salt, rather than to heat it to a lower temperature for a longer time, in order that fusion of the piezoelectric material may be confined to the layer thereof immediately in contact with the said electrode and adjacent thereto, whereby damage to the section is precluded.

In some instances it has been found desirable to provide means, such as an air current, for preventing the crystal sections, in their entirety, from reaching a dangerously high temperature during the welding operation. Such means is shown as an air hose **25** connected to a blower **27** and directed toward the sections **1**, **3** of crystalline material.

As a result of the welding operation the surfaces of the lead extension are caused to adhere firmly to the electroded surfaces of the crystal sections and the peripheries of the sections themselves fuse together to constitute an autogenous weld analogous to the joint obtained by practicing the method disclosed in the Pfundt patent. The central potrions of the opposed faces, however, are not connected to each other and they are, consequently, unrestrained during operation of the transducer.

The invention may also be practiced by passing a current directly through a lead extension from an appropriate potential source, either alternating or direct. In such event an extension of the type illustrated by Figure 4 may be employed with good results.

Because of the fact that the lead extension contacts the entire periphery of the conductive coating and because of the absence of cement, it has been found that multiplate transducers constructed according to the invention have lower input impedance than similar transducers of conventional type.

It will be apparent from the foregoing that the new and improved method, disclosed herein, reduces the number of manual operations heretofore considered necessary in fabricating a multiplate flexing element and, as one result, enables a reduction in factory cost. At the same time, electrical characteristics of the transducers produced thereby are quite uniform and the percentage of rejects materially reduced.

The inventor is fully aware of the fact that numerous modifications of the disclosed method and resultant product will be apparent to those skilled in the art, all within the scope of the invention. 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.

What is claimed is:

1. The method of electroding a face of a section of fusible piezoelectric matter, that comprises providing said face, over less than its total area, with a layer of electrically conductive material, providing said layer with a boundary element having conductivity materially higher than that of the layer, thereafter causing said element to be heated to a temperature sufficiently high to fuse the piezoelectric matter immediately in contact therewith and adjacent thereto and discontinuing the heating before damage is done to the remainder of the section, whereby said element is intimately bonded to the section and is held in conductive relation to the said layer at the boundary thereof.

2. The method as set forth in claim 1, characterized in this: that the piezoelectric matter is in the form of a section cut from a Rochelle salt crystal.

3. The method set forth in claim 1, characterized in this: that the piezoelectric matter is a mixed tartrate.

4. The method as set forth in claim 1, characterized in this: that the piezoelectric matter is a primary phosphate.

5. The method of causing a metallic lead extension, having the form of a closed loop, to adhere to the face of a section of fusible piezoelectric matter that has been provided previously with a restricted layer of electrically conductive material, which comprises pressing said lead extension into contact with said surface and the boundary of said layer, heating said lead extension to a temperature sufficiently high to fuse the piezoelectric matter in contact therewith, and discontinuing the heating before the remainder of the section reaches a temperature sufficiently high to militate against its piezoelectric properties, whereby the lead extension is firmly bonded to the section in conductive contact with the perimeter of said layer.

6. The method as set forth in claim 5, characterized in this: that the piezoelectric matter is a tartrate.

7. The steps in a method of fabricating transducer elements from at least two sections of crystalline piezoelectric matter each of which has an extended substantially planar face, that comprise placing electrically conductive material upon said faces, disposing between said faces in contact with the borders of said material a boundary element having higher electrical conductivity than the said material, urging said faces toward each other to exert pressure upon said boundary element, causing an electric current to flow in said element at such density as will cause fusion of the piezoelectric matter closely adjacent thereto and stopping the flow of current before fusion has extended to the remainder of each section.

8. The method as set forth in claim 7, characterized in this: that the boundary element is a closed loop.

9. The method as set forth in claim 7, additionally characterized in this: that the portions of the crystal sections remote from the conductive layer are maintained sufficiently cool during the heating cycle to prevent damage thereto.

10. The method as set forth in claim 7, additionally characterized in this: that the boundary element is constituted by a closed loop of metallic

foil or the like the area of which is materially less than the area of at least one of the coated surfaces with which it makes contact.

11. The method set forth in claim 7, characterized in this: that the piezoelectric matter is a tartrate.

12. The method set forth in claim 7, characterized in this: that the piezoelectric matter is a primary phosphate.

13. An assembly comprising at least two plates of fusible piezoelectric material disposed in face to face arrangement, the opposed faces each having a coating of electrically conducting material, a lead extension in the form of a closed loop interposed between the faces, said faces being united to each other adjacent their peripheries by a thin layer of fused material and being connected to said lead extension, the major portions of said opposed faces being free and unrestrained.

14. The method of electroding a face of a section of fusible piezoelectric crystalline material, that comprises: providing said face with a layer of electrically conductive material, providing said face with a boundary element having electrical conductivity higher than that of the layer, thereafter causing at least a portion of said section including said face to be heated to a temperature sufficiently high to fuse the piezoelectric matter immediately in contact with said conductive layer and said boundary element and discontinuing the heating before damage is done to the remainder of the section, whereby said boundary element is intimately bonded to the section in electrically conductive relation to the said layer.

15. The invention as set forth in claim 14, further characterized in this: that the boundary element is in the form of a closed metallic loop, and the heating is by induction.

16. The invention as set forth in claim 14, further characterized in this: that the boundary element is in the form of an open loop, and the heating is by resistance to the flow of electrical current through said boundary element.

17. The invention as set forth in claim 14, further characterized in this: that the portions of the crystalline material remote from the boundary element are maintained sufficiently cool during the heating of the face thereof to prevent damage thereto.

18. In the method of electroding a face of a section of fusible piezoelectric matter the steps of providing said face with a layer of electrically conductive material, providing said layer with a boundary element having conductivity materially higher than that of the layer, thereafter causing said element to be heated to a temperature sufficiently high to fuse the piezoelectric matter immediately in contact therewith and adjacent thereto and discontinuing the heating before damage is done to the remainder of the section, whereby said element is intimately bonded to the section and is held in conductive relation to the said layer at the boundary thereof.

19. The method as set forth in claim 18, further characterized in this: that said boundary element is metallic, and said element is heated by induction to cause fusion of the piezoelectric matter immediately in contact therewith.

20. The method as set forth in claim 18, further characterized in this: that said boundary element is metallic and it is heated by causing an electrical current to flow therethrough.

21. The method of causing a metallic lead extension to adhere to the face of a section of fusible piezoelectric matter that has been provided previously with a layer of electrically conductive material, which comprises pressing said lead extension into contact with said surface and into contact with at least a portion of said layer of conductive material, heating said lead extension to a temperature sufficiently high to fuse the piezoelectric matter in contact therewith, and discontinuing the heating before the remainder of the section reaches a temperature sufficiently high to militate against its piezoelectric properties, whereby the lead extension is firmly bonded to the section and is in conductive contact with said layer.

22. The method as set forth in claim 21, further characterized in this: that said lead extension is heated by induction.

23. The method as set forth in claim 21, further characterized in this: that said lead extension is heated by causing an electrical current to flow therethrough.

24. An assembly comprising at least two plates of fusible piezoelectric material disposed in face to face arrangement, the opposed faces each having a coating of electrically conducting material, an electrically conducting element in the form of a loop interposed between the faces, said faces being united to each other adjacent the edges of said electrically conducting element by a thin layer of fused material leaving the major portions of said opposed faces unattached.

25. An assembly as set forth in claim 24, further characterized in this: that said electrically conducting loop element is positioned substantially at the boundary of said opposed faces.

26. An assembly as set forth in claim 24, further characterized in this: that said electrically conducting loop element is a closed loop.

27. An assembly as set forth in claim 24, further characterized in this: that said electrically conducting loop element is an open loop.

28. An assembly as set forth in claim 24, further characterized in this: that said electrically conducting loop element is a closed loop positioned substantially at the boundary of said opposed faces.

29. An assembly as set forth in claim 24, further characterized in this: that said electrically conducting loop element is an open loop positioned substantially at the boundary of said opposed faces.

30. An assembly as defined in claim 24, characterized in this: that the piezoelectric material is a tartrate.

31. An assembly as defined in claim 24, characterized in this: that the piezoelectric material is a primary phosphate.

32. An assembly as defined in claim 24, characterized in this: that the piezoelectric material is a mixed tartrate.

33. An assembly as defined in claim 24, characterized in this: that the piezoelectric material is a primary arsenate.

JOHN P. ARNDT, JR.