Oct. 25, 1949. C. K. GRAVLEY 2,486,150

PIEZOELECTRIC TRANSDUCER AND METHOD FOR PRODUCING THE SAME

Filed Dec. 31, 1947

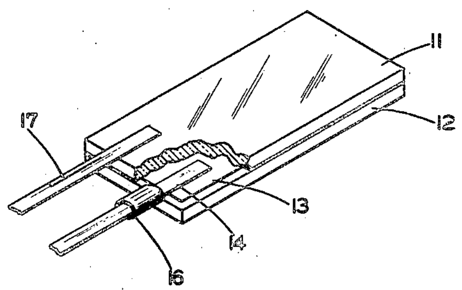

FIG. 1

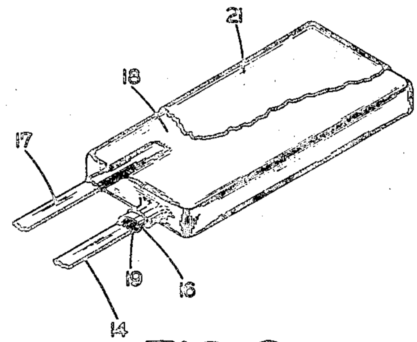

FIG. 2

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Patented Oct. 25, 1949 2,486,150

UNITED STATES PATENT OFFICE

2,486,150

PIEZOELECTRIC TRANSDUCER AND METHOD FOR PRODUCING THE SAME

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Application December 31, 1947, Serial No. 795,103

14 Claims. (Cl. 171—327)

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This invention relates to an improved piezoelectric transducer, and more particularly, to such a transducer of the type having a piezoelectric element at least partially covered or encased so as to make it more suitable for use in adverse surroundings such as an atmosphere high in moisture.

It has been proposed to treat nonmetallic surfaces by brushing on the surfaces a thick mixture made up of carbon particles in the form of graphite, a cementing material, and a small amount of water. When the water has dried and the cementing material has hardened, the coated surfaces are placed in an electrolyte and a metallic film deposited over the carbon particles.

If it is attempted to treat piezoelectric elements including crystal plates or bars in this manner, several difficulties arise. In the first place, it is impractical to form a thin conductive layer by applying the graphite mixture as a paste, and attempts to deposit carbon particles on the element from a more fluid suspension in a liquid may result in uneven distribution of the carbon particles on the crystalline surfaces, especially at the edge portions of the crystal plate or bar. Moreover, the liquid in which carbon particles are suspended may attack or dissolve the crystalline material. Further difficulties are encountered when a liquid containing carbon particles in suspension is applied and the liquid runs off or evaporates from the surfaces of the piezoelectric element, since there is a tendency for different surfaces to accept different thicknesses of the suspension and to dry and harden at different rates, causing thinning and checking the carbon layer, usually at the edge portions of the element. This tendency to check or crack may cause failure of the coating of carbon particles at any time during the handling of the element until the electro-deposited coating is completed, and failure of the carbon coating also may occur during electro-deposition due to the cementing material being dissolved or attacked by the electrolyte. A piezoelectric transducer coated in this way thus is subject to impairment of its operating efficiency or usefulness by reason of damage to the crystalline element or imperfections in the conductive coating.

It is an object of this invention, therefore, to provide a new and improved piezoelectric transducer which substantially avoids one or more of the limitations of prior transducers.

It is also an object of the invention to provide a method for producing such a piezoelectric transducer free of the limitations and disadvantages of prior methods for producing such transducers.

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It is another object of this invention to provide a new and improved piezoelectric transducer having a substantially moisture-impervious metallic coating so as to render bulky sealed containers unnecessary even under rather severe conditions of usage.

It is a further object of this invention to provide a new and improved method for producing a piezoelectric transducer having a thin metallic covering free of cracks and significant porosity.

It is a still further object of the invention to provide a new and improved piezoelectric transducer having an external electrode in the form of an electro-deposited film.

In accordance with one feature of the invention, a piezoelectric transducer comprises a piezoelectric element having nonconductive external surfaces. The transducer includes, over at least some of these surfaces, an under coating containing finely divided electrically conductive particles having such form and intimacy of contact as to provide a suitably conductive base for electroplating, cohesive material in this under coating, and a filamentary material in the under coating to reenforce and strengthen the undercoating, the filaments of the filamentary material near the outer surface of the under coating being substantially covered by the conductive particles. The transducer further comprises an outer coating of electro-deposited metal over the under coating.

In accordance with another feature of the invention, the method for producing a piezoelectric transducer comprises forming over at least some of the nonconductive external surfaces of a piezoelectric element an under coating containing finely divided electrically conductive particles having the desired form and intimacy of contact, including in this under coating a cohesive material and, to reenforce and strengthen said under coating, filamentary material the filaments of which near the outer surface of the under coating are adapted to be substantially covered by the conductive particles. The method includes electro-depositing an outer coating of metal over the under coating.

For a better understanding of the present invention, together with other and further objects thereof, reference is had to the following description taken in connection with the accompanying drawing and its scope will be pointed out in the appended claims.

In the single sheet of the drawing, Fig. 1 is an isometric view, partially broken away, of a multiplate piezoelectric element suitable for treatment in accordance with the present invention; and Fig. 2 is an isometric view of the same element which has been subjected to the several steps of a treatment in accordance with the present invention to form a piezoelectric transducer embodying the invention, the covering layer formed over the element by the last step of the treatment being shown largely broken away.

Referring to Fig. 1 of the drawing, there is shown a piezoelectric element of the multiplate type having an upper crystalline plate 11 and a lower crystalline plate 12. The upper surface of plate 11, the lower surface of plate 12, and the narrow sides of the plates are nonconductive external surfaces of the element, which has rather sharp edge portions at the junctions of the upper and lower surfaces with the sides. Between the plates 11 and 12 there is a thin conducting sheet 13 of a suitable material, which conveniently may be formed by applying graphite to the respective surfaces of the plates and cementing the prepared surfaces together. The sheet 13 forms an electrode both the length and width of which are somewhat less than the corresponding dimensions of the crystalline plates. This electrode 13 is centered with respect to the plates, and is provided with a lead 14 in the form of a thin strip of metal extending outwardly from between the plates 11 and 12.

During assembly of the piezoelectric element shown in Fig. 1 the plates 11 and 12 and the lead 14 were secured in place by means of a nonconductive cement which fills the interstices between the plates extending from the edges of the electrode 13 to the edges of the plates, thus sealing and insulating the electrode 13 from the exterior except where the lead 14 protrudes. To protect the lead 14 from contact with the metallic coatings, to be described hereinbelow, a small insulating conduit in the form of a short flexible tube 16 of a plastic material or a suitable fabric is slipped over the lead 14 so that one end of the tube abuts against the edges of the plates 11 and 12. To seal the tube 16, it is preferable to fill the tube by flowing a heated moisture-resistant wax into the space between the outer end of the tube and the lead strip 14. Some of the wax (not shown in Fig. 1) flows out the other end of the tube to seal that end against the sides of the crystal plates. A thin conductor or lead strip 17 also is affixed temporarily by means of cement to the outer surface of one of the plates, for example the plate 11.

In order to produce a moisture-resistant piezoelectric transducer from the piezoelectric element illustrated in Fig. 1, there first is formed a suspension of finely divided electrically conductive particles and a filamentary material in a volatile organic liquid medium, in which is dissolved a substantially water-insoluble cohesive material. A suitable nonaqueous liquid medium for the suspension is a mixture of normal heptane and normal butyl alcohol. These organic liquids may be mixed for this purpose in widely varying proportions, but a mixture containing about three parts heptane to one part butyl alcohol by weight or by volume is satisfactory.

The electrically conductive particles should be very finely divided, so that they are adapted to coat any crevices or protrusions on surfaces on which they are deposited, and particularly so that they are adapted to cover substantially the individual filaments of the filamentary material which is also in suspension in the volatile liquid. Such covering of the filaments near the outer surface of a film deposited from the suspension is important not only to insure that practically the entire surface of the coating is conductive, but also so that continuity of the surface does not depend to a great extent on bonding of carbon particles to filamentary particles protruding from the surface. Suitable for this purpose are particles of carbon, preferably in the form of acetylene black. These particles of acetylene black are adapted admirably to this purpose, and have such form as to provide upon deposition on either nonconductive or conductive surfaces a suitably conductive base for electroplating, provided the suspended matter in the liquid medium contains such conductive particles in substantial proportions, so that the intimacy of contact of the deposited particles of acetylene black with each other is not too greatly disturbed by intervening particles of filamentary and cohesive materials.

A suitable cohesive material which is substantially insoluble in the aqueous electrolytes ordinarily used in the electro-deposition of metals is an ethylcellulose resin to which is added a relatively small amount of a plasticizer such as dibutyl phthalate. An advantage of this organic cohesive material is that it is dissolved easily in the organic liquid used as a medium for the suspension. When the solvent medium evaporates, the cohesive resin comes out of solution and remains evenly distributed throughout the deposited material which had been suspended in the liquid medium.

It is desired to treat at least some of the nonconductive external surfaces of the piezoelectric element with a suspension of acetylene black to form over the treated surfaces upon evaporation of the liquid medium an under coating containing substantial proportions of the particles of acetylene black bonded by cohesive material in the under coating. It has been found, however, that an under coating containing only carbon particles bonded by the cohesive material and formed in this way tends to check due to uneven distribution of the coating over the surfaces, especially over the edge portions of the surfaces. This tendency to form checks or cracks is evident particularly during application and evaporation of the liquid medium, but may occur thereafter. It has been discovered, however, that this checking may be prevented by including in the suspension the filamentary material referred to hereinabove. Filaments of this material apparently serve to retain a more uniform film thickness at the edges when the suspension is applied to surfaces having rather sharp edge portions, and, being present in the coating remaining upon evaporation of the liquid medium from the applied film, these filaments serve to reenforce and strengthen the coating thus formed.

The filaments making up this filamentary material should be long enough to perform the uniform distribution and strengthening function, but not so long as to protrude from the coating. Satisfactory lengths of moderately flexible filaments lie generally in the range between 1/64 and 3/64 inch, although occasional filaments may be outside of this range of lengths. A suitable filamentary material may be produced by grinding asbestos fibers. Asbestos filaments having a maximum length of about 3/64 inch are moderately flexible, so that they conform somewhat to curvatures of the surfaces on which the coating is formed without being so flexible as to defeat the reenforcing function or to exhibit a tendency to bunch. An excess of under-sized filaments merely results in a coating of decreased conductivity without any compensating uniformity, reenforcement, or strengthening of the coating.

While the proportions of the materials in the suspension are not critical, a suitable suspension may be made by stirring one part by weight of acetylene black and two parts by weight of the ground asbestos filaments into 35 to 40 parts by weight of the organic liquid medium in which first is dissolved about two parts by weight of the plasticized ethylcellulose resin.

In treating the external surfaces of a piezoelectric element with the suspension to form a conductive under coating upon evaporation of the liquid medium, the suspension may be applied to the element in any convenient way, for example, by painting with a brush. However, it is preferred to form a suspension of such low viscosity that it may be maintained by gentle stirring in a trough, over which the piezoelectric element illustrated in Fig. 1 may be hung by suitable clamps fastened to the leads 14 and 17. The clamps then are lowered into the suspension until the element is submerged up to about the middle of the tube 16, after which the element is withdrawn slowly from the suspension and placed in a warm oven to hasten evaporation of the liquid medium.

The result of this operation is illustrated in Fig. 2 of the drawings. The leads 14 and 17 protrude from the deposited undercoating 18, containing the conductive particles of acetylene black, but the outer end of the tube 16 is sealed with the plug of wax mentioned hereinabove and designated 19. The coating 18 bonds the lead 17 to the element. It is noted that conductive surfaces, such as a portion of the top of the lead 17, as well as nonconductive surfaces are coated.

To complete the production of a moisture-resistant piezoelectric transducer, the under coating 18 now is provided with an outer coating 21 of electroplated metal, such as copper or tin, by electro-deposition from the usual aqueous electrolyte. Only the portion of the outer coating 21 covering one corner of the transducer is illustrated in Fig. 2. For the plating operation the element may be suspended in the plating bath by the leads 14 and 17 and electrical contact made through the lead 17. For example, an outer coating of about 0.0005 inch of copper serves to make the unit highly moisture-resistant. It is considered unnecessary to represent the entire outer coating in Fig. 2, since it is practically coextensive with the under coating 18 and covers the same surface areas.

By including the lead 17 in electrical contact with the under coating 18 there is provided a lead corresponding to another electrode of the transducer, this electrode being the external coating 21 itself. It is noted that the electrode referred to extends over the upper and lower surfaces respectively of both of the crystal plates 11 and 12, so that the electrode 13 between the plates is provided with two opposed electrode surfaces connected together in parallel. There thus is formed a multiplate piezoelectric transducer of a type generally well known in the art. For more detailed descriptions of such multiplate units, including the desired crystallographic orientation of the plates 11 and 12 and the general operating characteristics, reference may be had to United States Letters Patent Re. 20,213 and Re. 20,680, granted on December 22, 1936, and March 29, 1938, respectively, to Charles B. Sawyer and assigned to the same assignee as the present application.

While there has been described what at present is considered to be the preferred embodiment of this invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention. It is aimed, therefore, in the appended claims to cover all such changes and modifications which fall within the true spirit and scope of the invention.

What is claimed is:

1. A piezoelectric transducer comprising: a piezoelectric element having nonconductive external surfaces; an under coating over at least some of said surfaces containing finely divided electrically conductive particles having such form and intimacy of contact as to provide a suitably conductive base for electroplating; a cohesive material in said under coating; filamentary material in said under coating to reenforce and strengthen said under coating, the filaments of said material near the outer surface of said under coating being substantially covered by said conductive particles; and an outer coating of electro-deposited metal over said under coating.

2. A piezoelectric transducer comprising: a piezoelectric element having nonconductive external surfaces; an under coating over at least some of said surfaces containing finely divided carbon particles having such form and intimacy of contact as to provide a suitably conductive base for electroplating; a cohesive material in said under coating; filamentary material in said under coating to reenforce and strengthen said under coating, the filaments of said material near the outer surface of said under coating being substantially covered by said carbon particles; and an outer coating of electro-deposited metal over said under coating.

3. A piezoelectric transducer comprising: a piezoelectric element having nonconductive external surfaces; an under coating over at least some of said surfaces containing particles of acetylene black having such intimacy of contact as to provide a suitably conductive base for electroplating; a cohesive material in said under coating; filamentary material in said under coating to reenforce and strengthen said under coating, the filaments of said material near the outer surface of said under coating being substantially covered by said particles of acetylene black; and an outer coating of electro-deposited metal over said under coating.

4. A piezoelectric transducer comprising: a piezoelectric element having nonconductive external surfaces; an under coating over at least some of said surfaces containing finely divided electrically conductive particles having such form and intimacy of contact as to provide a suitably conductive base for electroplating; a cohesive material in said under coating; filamentary material in said under coating in the form of moderately flexible filaments generally $\frac{1}{64}$ to $\frac{3}{64}$ inch in length to reenforce and strengthen said under coating, the filaments of said material near the outer surface of said under coating being substantially covered by said conductive particles; and an outer coating of electro-deposited metal over said under coating.

5. A piezoelectric transducer comprising: a piezoelectric element having nonconductive external surfaces; an under coating over at least some of said surfaces containing finely divided

electrically conductive particles having such form and intimacy of contact as to provide a suitably conductive base for electroplating; a cohesive material in said under coating; asbestos filaments in said under coating to reenforce and strengthen said under coating, those of said filaments near the outer surface of said under coating being substantially covered by said conductive particles; and an outer coating of electro-deposited metal over said under coating.

6. A piezoelectric transducer comprising: a piezoelectric element having nonconductive external surfaces and rather sharp edge portions; an under coating over at least some of said surfaces containing finely divided electrically conductive particles having such form and intimacy of contact as to provide a suitably conductive base for electroplating; a cohesive material in said under coating; filamentary material in said under coating to reenforce and strengthen said under coating over said edge portions, the filaments of said material near the outer surface of said under coating being substantially covered by said conductive particles; and an outer coating of electro-deposited metal over said under coating.

7. A piezoelectric transducer comprising: a piezoelectric element having at least one electrode insulated from the external portions of said element and having nonconductive external surfaces; an under coating over at least some of said surfaces, insulated from said electrode and containing finely divided electrically conductive particles having such form and intimacy of contact as to provide a suitably conductive base for electroplating; a cohesive material in said under coating; filamentary material in said under coating to reenforce and strengthen said under coating, the filaments of said material near the outer surface of said under coating being substantially covered by said conductive particles; an outer coating of electro-deposited metal over said under coating; and conductive lead means in electrical contact with at least one of said coatings, thereby providing on said piezoelectric element another electrode of said transducer and a corresponding lead.

8. A moisture-resistant piezoelectric transducer comprising: a piezoelectric element having at least one electrode and at least one corresponding lead affixed thereto, at least one of said electrodes and the portion of its individual lead emerging from said element being insulated from the external portions of said element, and also having external surfaces at least some of which are nonconductive; an under coating over all of said external surfaces containing finely divided electrically conductive particles having such form and intimacy of contact as to provide a suitably conductive base for electroplating; a cohesive material in said under coating; filamentary material in said under coating to reenforce and strengthen said under coating, the filaments of said material near the outer surface of said under coating being substantially covered by said conductive particles; a substantially moisture-impervious outer coating of electro-deposited metal over said under coating; and moisture-resistant insulating and sealing means separating said coatings and said portion of said individual lead emerging from said element.

9. The method for producing a piezoelectric transducer comprising: forming over at least some of the nonconductive external surfaces of a piezoelectric element an under coating containing finely divided electrically conductive

particles having such form and intimacy of contact as to provide a suitably conductive base for electroplating; including in said under coating a cohesive material and, to reenforce and strengthen said under coating, filamentary material the filaments of which near the outer surface of said under coating are adapted to be substantially covered by said conductive particles; and electro-depositing an outer coating of metal over said under coating.

10. The method for producing a piezoelectric transducer, comprising: forming over at least some of the nonconductive external surfaces of a piezoelectric element an under coating containing particles of acetylene black having such intimacy of contact as to provide a suitably conductive base for electroplating; including in said under coating a cohesive material and, to reenforce and strengthen said under coating, asbestos filaments having a maximum length of about $^3/_{64}$ inch; and electro-depositing an outer coating of metal over said under coating.

11. The method for producing a piezoelectric transducer, comprising: forming a suspension of finely divided electrically conductive particles and a filamentary material in a volatile liquid medium in which is dissolved a cohesive material; treating at least some of the nonconductive external surfaces of a piezoelectric element with said suspension to form upon evaporation of said liquid medium an under coating containing said finely divided particles having such form and intimacy of contact as to provide a suitably conductive base for electroplating, bonded by said cohesive material, and reenforced and strengthened by said filamentary material the filaments of which near the outer surface of said under coating are adapted to be substantially covered by said conductive particles; and electro-depositing an outer coating of metal over said under coating.

12. The method for producing a piezoelectric transducer, comprising: forming a suspension of particles of acetylene black and a filamentary material in the form of moderately flexible filaments generally $^1/_{64}$ to $^3/_{64}$ inch in length in a volatile organic liquid medium in which is dissolved a substantially water-insoluble cohesive material; treating at least some of the nonconductive external surfaces of a piezoelectric element with said suspension to form upon evaporation of said liquid medium an under coating containing said finely divided particles having such intimacy of contact as to provide a suitably conductive base for electroplating, bonded by said cohesive material, and reenforced and strengthened by said filamentary material the filaments of which near the outer surface of said under coating are substantially covered by said particles of acetylene black; and electro-depositing an outer coating of metal over said under coating.

13. The method for producing a piezoelectric transducer, comprising: forming a suspension of finely divided electrically conductive particles in a volatile liquid medium in which is dissolved a cohesive bonding material; treating at least some of the nonconductive external surfaces of a piezoelectric element having rather sharp edge portions with said suspension to form upon evaporation of said liquid medium an under coating containing said finely divided particles having such form and intimacy of contact as to provide a suitably conductive base for electroplating; including in said suspension used to form said under coating, to reenforce and

strengthen said under coating and to minimize the tendency of said coating to become thin at said edge portions during the formation of said coating, filamentary material the filaments of which near the outer surface of said under coating are adapted to be substantially covered by said conductive particles; and electro-depositing an outer coating of metal over said under coating.

14. The method for producing a moisture-resistant piezoelectric transducer from a piezoelectric element having at least one electrode insulated from the external portions of said element and at least one corresponding lead affixed to said one electrode, comprising: providing the portion of said lead emerging from said element with an insulating conduit and sealing said conduit with a moisture-resistant material to the external surfaces of said element and to said lead; forming over all of the external surfaces of said element, at least some of which are nonconductive, and over the portions of said sealed insulating conduit adjacent said external

surfaces an under coating containing finely divided electrically conductive particles having such form and intimacy of contact as to provide a suitably conductive base for electroplating; including in said under coating a cohesive material and, to reenforce and strengthen said under coating, filamentary material the filaments of which near the outer surface of said under coating are adapted to be substantially covered by said conductive particles; and electro-depositing a substantially moisture-impervious outer coating of metal over said under coating.

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