Dec. 31, 1940. W. P. MASON 2,227,268

PIEZOELECTRIC APPARATUS

Filed April 5, 1939 2 Sheets-Sheet 1

FIG. 1

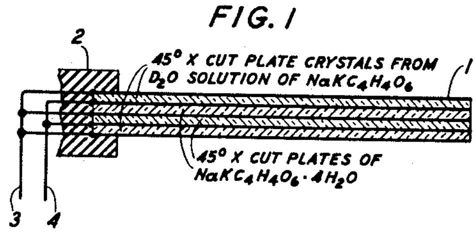

FIG. 2

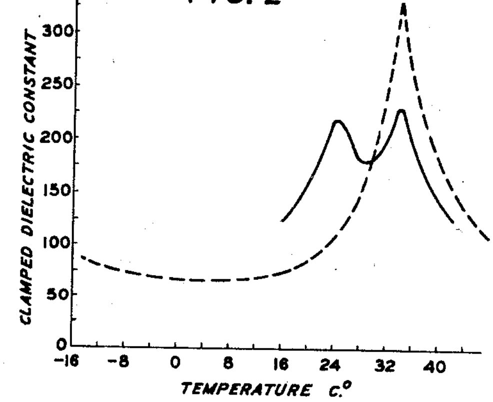

FIG. 3

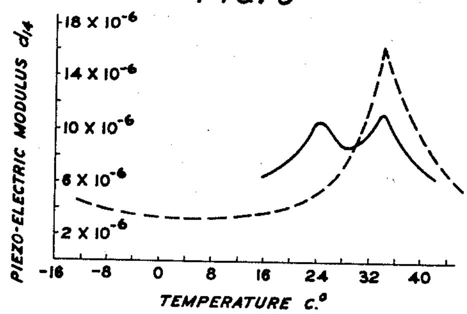

FIG. 4

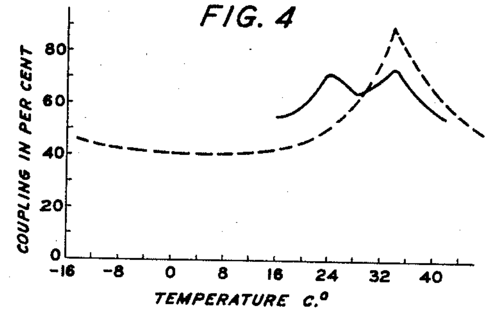

FIG. 5

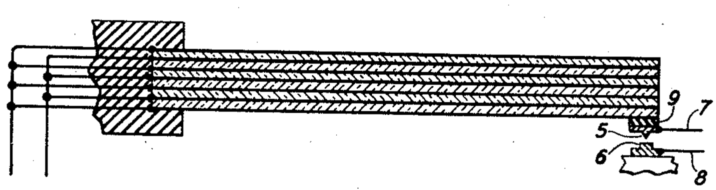

FIG. 6

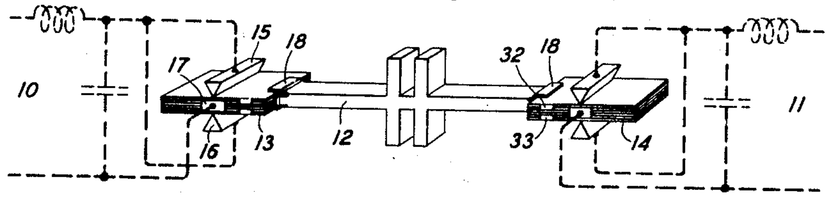

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FIG. 7

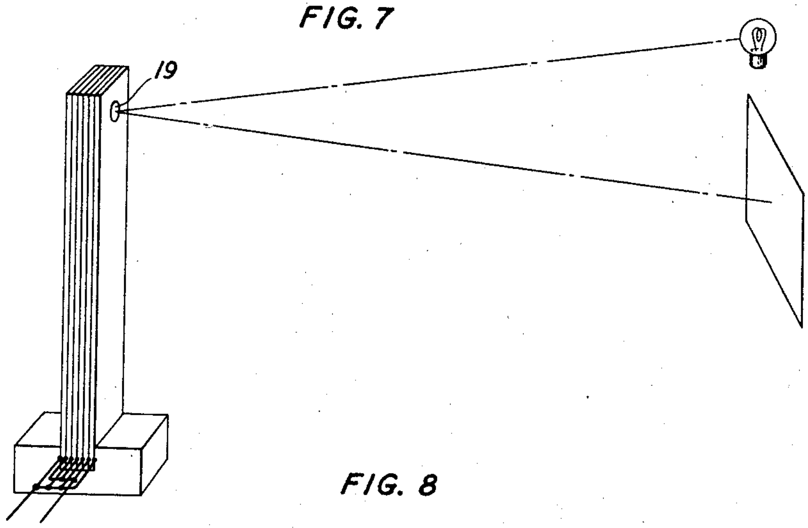


FIG. 8

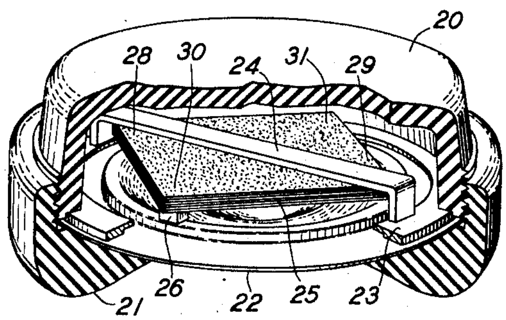
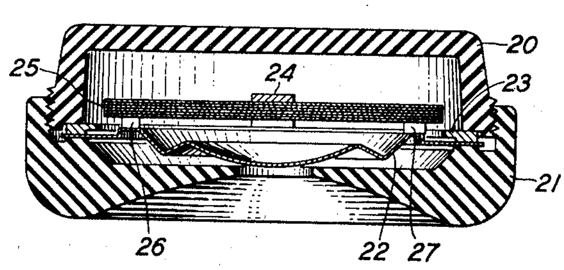


FIG. 9



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2,227,268

PIEZOELECTRIC APPARATUS

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Application April 5, 1939, Serial No. 266,072

15 Claims. (Cl. 171—327)

This invention relates to piezoelectric apparatus and more particularly to electromechanical devices utilizing piezoelectric elements of the sodium potassium tartrate type.

An object of the invention is to increase the temperature range over which piezoelectric devices of the sodium potassium tartrate type are efficient.

Other objects of the invention are to provide a piezoelectric unit of the sodium potassium tartrate type having impedance, a displacement per unit of applied voltage, and an electromechanical coupling factor which are nearly constant over a wide temperature range.

In accordance with the invention piezoelectric devices are formed by plates of ordinary sodium potassium tartrate having their greatest efficiency in the temperature range of 16° to 28° centigrade, interspersed with plates of sodium potassium tartrate crystallized from heavy water (deuterium oxide) and having their greatest efficiency in the temperature range extending from 28° to 42° centrigrade. Thus, the composite device is made efficient over a wide temperature range greatly exceeding that of devices of the Rochelle salt type hitherto available. The principle of the invention may be carried still further by including a third type of plate as, for example, a modification of Rochelle salt containing an isomorphous substance such as sodium rubidium tartrate. Such a plate will have a Curie point and a temperature range of highest efficiency occurring below that of ordinary Rochelle salt. Such a unit may be made to give a response which does not vary appreciably over a wide temperature range.

Piezoelectric devices comprising sodium potassium tartrate crystallized from deuterium oxide and the method of producing such devices are disclosed in U. S. Patent 2,188,154 issued January 23, 1940, to S. O. Morgan. For relays and other devices which are called upon to deliver a constant force for a constant applied voltage, the static characteristic of the piezoelectric material is of most interest. The piezoelectric constant d_{14} which measures the extension per unit length for unit applied electrical potential of the deuterium oxide sodium potassium tartrate crystal has been found by measurement to be approximately 17×10^{-6} for the temperature range of 20° centigrade up to 33° centigrade (92° F.). Above 32° centigrade the displacement and force exerted by heavy water sodium potassium tartrate decreases with increasing temperature.

The use of piezoelectric elements in dynamic devices such as receivers or transmitters depends to a greater extent upon the dynamic characteristics of the elements. Accordingly, for such applications the characteristics of impedance and of the coupling constant are of prime importance. As a matter of fact, a dynamic device employing a heavy water sodium tartrate piezoelectric crystal responds efficiently at a higher temperature than does one employing an ordinary Rochelle salt crystal but its response as the temperature varies is also subject to the difficulty of rapid change in efficiency as the temperature departs from the Curie point. If, however, a piezoelectric unit be constructed of interspersed plates of the two substances it will have a much more nearly constant impedance and efficiency over a relatively wide temperature range.

The principle of the invention will be more readily understood by reference to the following drawings in which Fig. 1 illustrates a piezoelectric structure, embodying the invention, arranged for longitudinal vibration;

Figs. 2, 3 and 4 show graphs of physical characteristics of piezoelectric elements of sodium potassium tartrate crystallized from deuterium oxide in comparison with the same characteristics for combinations of ordinary sodium potassium tartrate elements with those crystallized from deuterium oxide;

Fig. 5 illustrates schematically a piezoelectric relay utilizing bending vibration;

Fig. 6 illustrates an embodiment of the invention in which longitudinally vibrating piezoelectric elements are employed as the electromechanical coupling units of a wave filter;

Fig. 7 shows a light valve including a composite piezoelectric unit employing elements of three different Curie points;

Fig. 8 shows a telephone receiver embodying the invention with the cap of the receiver partly broken away, and

Fig. 9 is a sectional view of the telephone receiver of Fig. 8.

Referring to Fig. 1, there is shown a piezoelectric unit consisting of four thin plates of piezoelectric material each suitably coated on its opposite faces with conducting material or foil **1**, the plates being assembled in superposed position and held clamped at one end by clamping holder **2** of suitable insulation material. The conducting coatings or electrodes are connected by leads to the pair of conductors **3, 4**. The two inner plates may consist of ordinary Rochelle salt, $NaKC_4H_4O_6.4H_2O$, cut in well-known manner with their thickness parallel to the X axis and with their length dimension at an angle of 45° to the Y and

Z axes. The two plates are so positioned that when their adjacent conducting electrodes connected to the conductor **3** are similarly polarized by an electromotive force applied to the conductors **3** and **4** the plates extend in length together or contract together depending upon the polarity of the electromotive force. The two outer plates are similarly constructed and arranged but differ from the inner plates in that they each consist of material crystallized from a solution in deuterium oxide of sodium potassium tartrate from which the water has been previously removed in accordance with the disclosure of the U. S. Patent 2,188,154 to S. O. Morgan to which reference has been made. Accordingly, when an electromotive force of proper polarity is applied to conductors **3** and **4** all four plates extend in length and when an electromotive force of opposite polarity is applied all four plates contact. Since the structure is symmetrical about the plane separating the two inner plates any differences in the piezoelectric performance of the two different piezoelectric substances will not result in a bending or warping action and the principal vibration will be of the extensional type.

Fig. 2 illustrates in the dotted line graph, the variation in magnitude of the dielectric constant of the deuterium oxide crystal plates of Fig. 1 for various temperatures as compared with the solid line graph showing the corresponding characteristic for the composite structure of Fig. 1. It will be noted that the dielectric constant of the deuterium oxide crystal reaches a sharp peak at about 34.5° centigrade and that its high magnitude region is confined to a relatively narrow temperature range. The composite unit is double peaked and its magnitude does not attain the peak value of that of the deuterium oxide crystal but its characteristic is very much more uniform with temperature and it maintains a relatively high value over a temperature range of nearly 30° centigrade. Since the dielectric constant is an important characteristic entering into the electrical impedance of such a device it will be apparent that the composite unit is greatly superior to the single substance unit in commercial applications where the surrounding temperature is subject to variation.

Fig. 3 shows the piezoelectric modulus d_{14}, the dotted line graph for the heavy water crystal and the solid line graph for the combined structure of Fig. 1 and indicates that the uniformity of response of the composite device is markedly greater than is that of the single substance unit. A similar result is indicated by the corresponding graph of Fig. 4 showing the per cent coupling with variation in temperature.

Fig. 5 shows an electromechanical relay which relies upon bending action to carry its movable contact element **5** into engagement with stationary contact **6**, thus closing the circuit of conductors **7**, **8**. A strip **9** of insulating material serves to carry the contact element **5** to cause it to partake of the lateral motion of the relay unit while at the same time insulating the contact element from the conducting coating of the adjacent piezoelectric plate. The piezoelectric unit comprises six plates similar in their general structure and orientation or "cut" to those of Fig. 1. The central two may be of ordinary sodium potassium tartrate, $NaK_4H_4O_6.4H_2O$, as in Fig. 1 but one of these plates is reversed in its thickness direction so that it will extend or lengthen when the other contracts and vice versa in the manner of the well-known Curie bilame. The immediately adjacent pair of piezoelectric plates like those of Fig. 1 may consist of material crystallized from deuterium oxide solution of sodium potassium tartrate from which all water was removed prior to dissolution in the deuterium oxide as explained in the Morgan application. These two plates are likewise so arranged that the one extends when the other contracts and also that each extends at the same time as the adjacent plate of the central pair. The two outer plates may consist of a still different material such as, for example, a mixture of ordinary sodium potassium tartrate containing a percentage of sodium rubidium tartrate $NaR_bC_4H_4O_6.4H_2O$ of the order of .1 to .3 per cent. Such a material, as is disclosed in the application of W. P. Mason, Serial No. 233,530 filed November 3, 1938, for Piezoelectric apparatus, may be made to have a Curie point at a desired temperature below that of the Curie point of ordinary sodium potassium tartrate as for example at 14° centigrade. Accordingly, the characteristics of the composite device will be still further broadened over those of the Fig. 1 structure by the extension in the lower temperature range. The two outer plates will, of course, be arranged so that one extends when the other contracts. The three plates at one side of the device will, therefore, extend together and the other three contract together with a consequent lateral displacement such as that of the familiar bimetallic thermostat.

Fig. 6 shows an electromechanical wave filter in which circuits **10** and **11** are coupled to a longitudinally vibrating mechanical bar **12** by the piezoelectric units **13** and **14**. Each of the units **13** and **14** is arranged to have all of its six individual piezoelectric plates extend and contract simultaneously as in Fig. 1. The plates may consist of pairs of each of the three materials as disclosed in Fig. 5 to broaden the temperature range over which the device may yield an effective response. Each unit may be held between clamping members **15** and **16**. The electrical connections may be made in the manner of Fig. 1 with the two outside coatings and the alternate coatings with their projecting foil leads **32** and **33** connected to one terminal and the remaining coatings connected to the other through a strip of foil **17** at the margin of the device. Member **12** may be firmly glued or otherwise held fixed to the devices **13** and **14** at its ends. For this purpose it is provided with flanges **18** to overlap the surfaces of the devices. Care must be taken to insure that the member **17** is insulated from all of the coatings so as not to short circuit any of the piezoelectric plates or introduce detrimental capacity.

Fig. 7 illustrates a six plate unit similar in every respect to that of Fig. 5 arranged for bending action and provided with a mirror **19** to serve as a light valve or oscillograph in conjunction with a source of light **20**.

Figs. 8 and 9 show a telephone receiver of the type disclosed in application Serial No. 255,817, filed February 11, 1939, by T. J. Pope utilizing a piezoelectric driving unit embodying one form of the invention. It comprises a casing **20** of suitable dielectric material externally threaded to receive an apertured cap **21** of well-known type. The cap serves to clamp a diaphragm **22** also of well-known type against a metallic ring **23** to which is attached a U-shaped bar **24** extending diametrically across the ring. An assemblage **25** of three pairs of rectangular X cut plates of piezoelectric material is cemented to the bar **24** at the two diagonally opposite corners of the assemblage adjacent the ends of the bar. The other two corners of the assemblage are held fixed with respect to ring **23** by small blocks **26** and **27** of suitable insulating material which are cemented to both the assemblage and to the diaphragm. As in the structure of Fig. 5 the central pair of plates consists of one substance, the outermost pair of a second and the intermediate pair of a third substance. Each plate is preferably of a X cut with its length and width dimensions parallel respectively to the Y and Z axes. When subjected to an electric field in the direction of the X axis or thickness such a plate extends in the direction of one of its principal diagonals and contracts in the direction of its other principal diagonal. The plates of the central pair are so arranged that when one, for example, the upper, extends or increases its dimension parallel to bar **24** and contracts along the diagonal transverse to the bar, the lower extends in a direction transverse to the bar and contracts in the direction parallel to the bar. Accordingly, the pair of plates as a whole will warp in such manner that elements parallel to the bar **24** will bow upward at the center thus forcing downward the corners **28** and **29** adjacent the ends of bar **24**. At the same time elements transverse to the bar will bow in the opposite direction carrying the corners **30** and **31** adjacent blocks **26** and **27** up with respect to the center. It will, therefore, be seen that the corners **30** and **31** are given a double displacement upwardly with respect to corners **28** and **29** thus impelling the diaphragm **22** upward toward the bar **24**.

The upper plates of the central and outer pair are arranged so as to extend in the same direction with the upper plate of the intervening pair; the three lower plates also all extend simultaneously in the transverse direction. Upon reversal of the electric field the diaphragm will be impelled in the opposite direction. The plates may be electrically connected to the terminals of the driving circuit in any suitable manner and the two leads to which the electrode surfaces are alternately connected may be passed through the insulating receiver shell in the usual manner. This conventional structure is not shown in the interest of simplification of the drawings. In each of the structures described there is a physical symmetry about the plane of the common electrode of the central pair. For every plate lying at one side of that plane there is a companion plate symmetrically placed at the opposite side of the plane and consisting of the same piezoelectric substance.

What is claimed is:

1. A piezoelectric apparatus having an effective piezoelectric characteristic of a magnitude of the order of that of Rochelle salt and much more nearly uniform over a relatively wide temperature range comprising a plurality of elements of piezoelectric material each having electrodes to enable stimulating electric fields to be employed, the elements being mechanically connected to give a combined response which is a function of the individual responses of each, and the material of which the respective elements consist having different Curie points whereby the response of the apparatus is more uniform over a wide temperature range than is the response of any one of its constituent elements.

2. A piezoelectric structure of the Rochelle salt type having a constant $d14$, relating extension per unit length to electric field per unit area which throughout the range of temperatures 22° to 36° centigrade is in excess of eight times 10^{-6} the structure comprising a plurality of piezoelectric materials of the Rochelle salt type having respectively different Curie points.

3. A piezoelectric structure of the sodium potassium tartrate type having an efficient response over a range of temperatures wider and extending to a higher temperature limit than has ordinary sodium potassium tartrate, including an element of ordinary sodium potassium tartrate and an element of sodium potassium tartrate crystallized from deuterium oxide, each element being provided with electrodes to respond to the same applied electromotive force and being mechanically connected to each other to give a joint response.

4. A piezoelectric structure of the sodium potassium tartrate type having an efficient response over a range of temperatures wider and extending to a higher temperature limit than does ordinary sodium potassium tartrate, comprising an element of ordinary sodium potassium tartrate and another element consisting of an isomorphous substance having a higher Curie point, each element being provided with electrodes to permit application of the same electromotive force and the elements being mechanically coupled to give a joint response.

5. A piezoelectric structure of the sodium potassium tartrate type having an efficient response over a range of temperatures wider and extending to a lower temperature limit than does the response of ordinary sodium potassium tartrate, comprising an element of ordinary sodium potassium tartrate and another element consisting of a mixture of sodium potassium tartrate and sodium rubidium tartrate each provided with electrodes to respond to the same electromotive force and mechanically connected to each other to give a joint response.

6. A piezoelectric structure of the sodium potassium tartrate type having an efficient response over a range of temperatures wider and extending to a lower temperature limit than does the effective response of ordinary sodium potassium tartrate, comprising an element of ordinary sodium potassium tartrate and another element of an isomorphous material having a lower Curie point, each element being provided with electrodes to respond to the same applied electromotive force and the elements being mechanically connected to give a joint response.

7. A light valve comprising a plurality of piezoelectric elements of the sodium potassium tartrate type each provided with electrodes to enable application thereto of an actuating electromotive force, the electrodes being clamped at one end and fixed together at their free ends to operate as a unit, the orientation of each element being such that on one side of the assemblage there is a tendency for elongation at the same time that at the other side there is a tendency to contract whereby warpage occurs, one of said elements consisting of a substance different from that of another and having a different Curie point, and a mirror carried by the assemblage at the free end.

8. A piezoelectric apparatus comprising a plurality of individual piezoelectric plates each provided with electrodes, the plates being physically connected with respect to each other to cause the assemblage to operate as a unit, at least two of the plates consisting of the same substance and at least two others of the plates consisting of a shubstance having a Curie point different from the first-mentioned substance.

9. A piezoelectric apparatus comprising a plurality of individual piezoelectric plates each provided with a pair of electrodes, means for holding all the plates together to undergo deformations as a unitary assemblage, one pair of the plates consisting of the same piezoelectric substance and another pair consisting of a different piezoelectric substance having a Curie point different from the first-mentioned substance, the plates being stacked in such manner that the central pair are of the same substance and the plates of said other pair are respectively immediately adjacent to and just outside the plates of the central pair.

10. The combination of claim 9, characterized in this that means is provided for subjecting all the plates to an electric field in such direction as to cause them all to simultaneously extend in the same direction.

11. The combination of claim 9, characterized in this that means is provided for subjecting all the plates to an electric field in such direction as to cause those lying at one side of the common electrode plane of the central pair all to extend in the same direction while simultaneously those at the other side contract in that direction.

12. The combination of claim 9, characterized in this that means is provided for subjecting all the plates to an electric field in such direction as to cause those lying at one side of the common electrode plane of the central pair to extend together in the same direction and those at the opposite side of the common plane to simultaneously extend in a transverse direction whereby the unitary assemblage undergoes a warping action.

13. The combination of claim 8, characterized in this that a pair of plates of each of three different Curie point piezoelectric substances is employed.

14. A piezoelectric structure of the sodium potassium tartrate type having efficient response over a range of temperatures wider and extending to both lower and higher temperature limits than does the response of ordinary sodium potassium tartrate, comprising an element of ordinary sodium potassium tartrate, a second element consisting of an isomorphous substance having a higher Curie point, a third element consisting of an isomorphous substance having a lower Curie point, a driving means for the three elements subjecting each of them to an electric field derived from a common controlling source, and means for mechanically coupling the elements together to cause them to give a joint response.

15. An energy transfer structure comprising a piezoelectric element of the sodium postassium tartrate type, a second piezoelectric element of an isomorphous substance having a different Curie point, an input circuit, an output circuit, means electrically connected to the input circuit for subjecting each of said piezoelectric elements to an electric field stress, and means connected to the output circuit for controlling the output circuit in accordance with the joint response of the piezoelectric elements.

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