Nov. 1, 1949. R. B. GRAY 2,486,560

TRANSDUCER AND METHOD OF MAKING THE SAME

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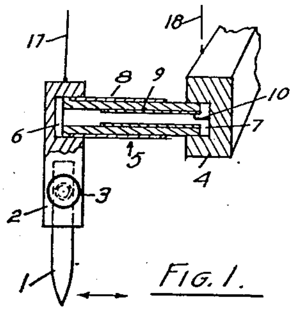

FIG. 1.

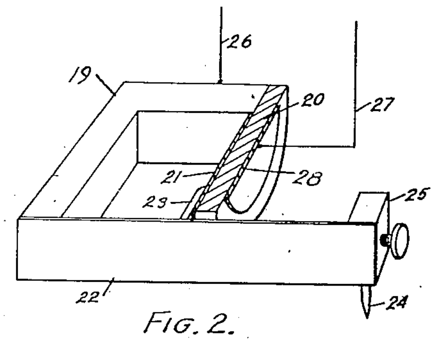

FIG. 2.

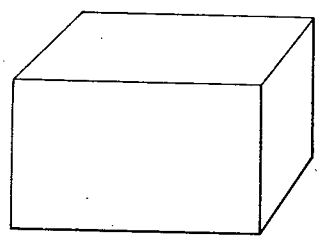

FIG. 3.

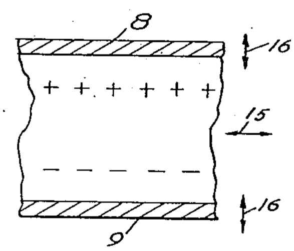

FIG. 4.

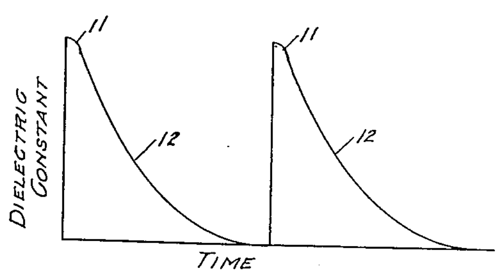

FIG. 5.

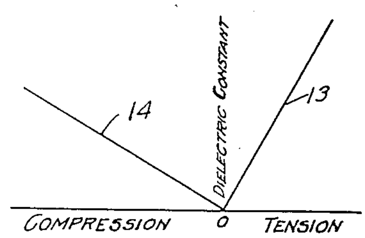

FIG. 6.

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TRANSDUCER AND METHOD OF MAKING THE SAME

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15 Claims. (Cl. 171—327)

1

This invention is a transducer for translating mechanical vibrations to alternating electrical voltages of corresponding wave form making use of a ceramic such as $BaTiO_3$ in tetragonal crystalline state.

In a preferred form the ceramic is subjected to a charging voltage and also to a mechanical stress while cooling from the temperature range at which the crystalline structure transforms from the cubic to the tetragonal. As the ceramic is cooled below the transformation temperature a portion of the charge is in effect permanently fixed or bound on the interfaces of the crystals producing in effect a ceramic electret. Both the charging voltage and the mechanical stress contribute to the orientation of tetragonal crystals in the preferred direction. The permanent charge results in a piezo-electric effect when the crystal is subjected to mechanical vibration. The response is linear. One use is for phonograph pickups where the mechanical ruggedness and ability to withstand extreme temperatures are additional practical advantages. Other uses are in microphones and speakers. Further objects appear in the specification and claims.

In the drawing, Fig. 1 is an end elevation of a phonograph pickup; Fig. 2 is a perspective view of a modification; Fig. 3 is a perspective of one of the tetragonal crystals; Fig. 4 is a diagrammatic view illustrating the production of the piezo-electric effect by the bound charges; Fig. 5 is a diagram showing the effect of tension and compression on the dielectric constant; Fig. 6 is a diagram illustrating the exponential decay of changes in dielectric constant produced by mechanical or electrostatic stress.

Referring to the drawing, 1 indicates a phonograph needle held in a metal chuck 2 by a thumb screw 3, and 4 indicates a metal block fixed in the arm. Between the chuck and block is a tubular ceramic condenser 5 having its ends fixed in sockets 6 and 7 in the chuck and block. An outer metalized coating 8 is soldered to the chuck and an inner metalized coating 9 is connected by a lead 10 to the block. The coatings are the condenser electrodes.

The ceramic comprises poly-crystalline $BaTiO_3$ having a substantial part in the tetragonal crystalline state. In the manufacture, the $BaTiO_3$ is mixed with addition agents such as clay or bentonite primarily for the purpose of making the mixture easier to work, and is then pressed into shape and fired at an elevated temperature, e. g. 2200°–2500° F. to form a dense ceramic. High temperature firing and addition agents such as

2

bentonite which promote grain growth and increase the crystal size are preferred. The metal coatings 8 and 9 are then applied, for example as a silver paint, and fixed by firing at from 250° to 1400° F. The condenser is then activated by heating the condenser to the transformation temperature of about 120° C. while applying a voltage between the coatings 8 and 9 until the condenser has cooled below the transformation temperature. It is not necessary that the voltage be continuously applied until the ceramic has cooled below the transformation temperature, although it is preferable. At temperatures above the transformation temperature, or more accurately, above the range of temperatures at which the transformation takes place, $BaTiO_3$ has a cubic crystal structure. Below the transformation temperature the crystal structure is predominantly tetragonal, as shown in Fig. 3, comprising two square end faces of 3.99 Angstrom units on each side and four rectangular faces having a length of 4.03 Angstrom units. There may be some cubic crystals remaining. The voltage between the coatings produces a permanent polarization probably resulting from charges on the interfaces of the crystals. In effect the activated condenser is a ceramic electret as diagrammatically indicated in Fig. 4.

In the tetragonal state an electric or mechanical stress produces a sudden increase in dielectric constant as indicated by the peaks 11 in Fig. 5. As the stress is continued, the dielectric constant decays exponentially with time as indicated by the curves 12. The increase in dielectric constant is linearly proportional to the stress and twice as rapid for tension stress as for compression stress as indicated by the curves 13 and 14 in Fig. 6. Because the slope for compression stress is different from the slope for tension stress, distortion would be introduced if the change in dielectric constant and the resultant change in capacity between the coatings 8 and 9 were utilized to effect the translation between electrical and mechanical vibrations.

When activated to produce the permanent or bound charge, there is a linear translation between alternating mechanical stress along the axis of the condenser and the voltage appearing between the coatings 8 and 9. This is apparently due to elastic deformation of the tetragonal crystals. It may be due in part to an adiabatic transformation of the tetragonal crystals with the long axis in the direction of stress to tetragonal crystals with the long axis at right angles to the direction of stress. Part of the effect may be due to change of the tetragonal crystals toward the cubic. A vibratory stress in the direction of the arrow 15 in Fig. 4 produces a movement of the coatings 8 and 9 in the direction of the arrows 16 and results in the production of a corresponding induced voltage between the coatings 8 and 9. Conversely, the application of an alternating voltage across the coatings 8 and 9 results in a corresponding elongation and contraction of the length of the condenser. The effect produced is similar to a piezo-electric effect. The absence of air between the coatings and ceramic increases the piezo-electric effect. When used as a phonograph pickup, the lateral movement of the needle as it tracks in the record groove produces an endwise stress on the tubular ceramic and results in a radial movement of the coatings 8 and 9, producing a voltage on the coatings which appears across leads 17 and 18, the voltage being proportional to the amplitude of the needle movement. The linearity is maintained over the audio range.

In the pickup shown in Fig. 1, the tetragonal crystals are oriented along the axis of the ceramic tube by the charging voltage applied to the coatings 8 and 9 while cooling from the transformation temperature. The orientation is due solely to the electrical stress. In Fig. 2 is shown a pickup in which the ceramic is also mechanically stressed, thereby producing a better or more complete orientation. Both stresses have the same orienting direction. The added mechanical stress permits more complete orientation without excessive charging voltages.

In Fig. 2 an angular metal block 19 fixed in the tone arm has a $BaTiO_3$ ceramic disc condenser 20 having a metalized coating 21 soldered on one face to one arm of the block and a strip spring 22 soldered to the other arm of the block. A metal bracket in the plane of the disc is soldered to the coating 21 and the spring 22 while the spring is bent toward the condenser. The amount of tension is controlled by the stiffness of the spring and the amount of bending. While the ceramic is under tension, it is heated to and then cooled from the transformation temperature while a charging voltage is applied between the coating 21 and a metal coating 23 on the opposite face. Both the tension and the charging voltage contribute to orientation of the tetragonal crystals in the plane of the disc. In use the block, 19, is mounted in the tone arm so the spring, 22, extends along the record groove. A needle, 24, in a chuck, 25, on the projecting end of the spring transmits the undulation of the groove to the condenser as a mechanical vibration in line with the orientation of the tetragonal crystals produced by the spring tension. This results in a voltage between the coatings, 21 and 23, appearing in leads, 26 and 27, linearly proportional to the amplitude of the needle movement. The voltage is somewhat greater due to the better or higher percentage preferred orientation of the tetragonal crystals.

Other titanates exhibit the same properties as barium titanate but the transformation temperature is too low to be practical. There is a possibility of mixing other titanates with barium titanate obtaining a solid solution with a lowered but still practical transformation temperature. Additions of from 4–5% calcium titanate drop the transformation temperature to about 55° C. Higher percentages do not drop the transformation temperature further indicating a saturation of the solid solution. The excess is in effect merely an inert ingredient. Additions of strontium titanate go into solid solution in percentages of over 28% apparently without saturation limit. At 28%, the transformation temperature is at the impractically low value of 13° C. A wide variety of ingredients which do not affect the transformation temperature may be added. Among these are ingredients for increasing the workability, for promoting grain growth, for controlling the firing temperature and for other purposes known to the ceramic condenser art.

Among the advantages of the barium titanate transducer are low cost, mechanical strength and resistance to shock, high output and linear response, and stability. The change in performance with temperature and aging is not objectionable. If the activation should be destroyed by an excessively high temperature the transducer can be easily reactivated.

What I claim as new is:

1. A transducer having as an active ingredient barium titanate in tetragonal crystalline state.

2. A transducer having as an active ingredient barium titanate polarized by bound charges.

3. A transducer having as an active ingredient barium titanate in tetragonal crystalline state stressed at the transformation temperature to orient the crystals in the preferred direction.

4. A transducer having as an active ingredient barium titanate in tetragonal crystalline state with the crystals oriented in the direction of vibratory movement.

5. A transducer having as an active ingredient barium titanate in tetragonal crystalline state with the crystals oriented in the direction of vibratory movement and polarized in a direction transverse to the direction of vibratory movement by bound charges.

6. A transducer comprising a ceramic having spaced faces provided with metalized coatings, said ceramic having as an active ingredient barium titanate in tetragonal crystalline state with the crystals oriented along the faces and polarized in a direction transverse to the faces by bound charges.

7. A transducer comprising a ceramic having spaced faces provided with metalized coatings, said ceramic having as an active ingredient a solid solution of barium titanate in tetragonal crystalline state with the crystals oriented along the faces and polarized in a direction transverse to the faces by bound charges.

8. A phonograph pickup comprising a ceramic with spaced metalized coatings extending along the direction of movement produced by the record groove, said ceramic having as an active ingredient poly-crystalline barium titanate in tetragonal crystalline state with the crystals oriented along said direction of movement and polarized transverse to said direction of movement by bound charges.

9. A phonograph pickup comprising a ceramic with spaced metalized coatings extending along the direction of movement produced by the record groove, said ceramic having as an active ingredient poly-crystalline barium titanate in tetragonal crystalline state polarized transverse to said direction of movement by bound charges.

10. A phonograph pickup comprising a ceramic with spaced metalized coatings extending along the direction of movement produced by the record groove, said ceramic having as an active ingredient poly-crystalline barium titanate in tetragonal crystal line state treated to promote grain

growth and polarized transverse to said direction of movement by bound charges.

11. The method of activating a barium titanate ceramic to produce a piezo-electric effect which comprises subjecting the ceramic to a polarizing voltage at the temperature at which the crystals transform from the cubic to the tetragonal.

12. The method of making a transducer which comprises treating a barium titanate ceramic to promote grain growth, and subjecting the ceramic to a polarizing voltage at the temperature at which the crystals transform from the cubic to the tetragonal.

13. The method of making a transducer which comprises subjecting a barium titanate ceramic to a polarizing voltage and a mechanical stress tending to orient the tetragonal crystals in a direction transverse to the direction of polarization at the temperature at which the crystals transform from the cubic to the tetragonal.

14. The method of making a transducer which comprises subjecting a barium titanate ceramic to a polarizing voltage and a tension stress transverse to the direction of polarization at the temperature at which the crystals transform from the cubic to the tetragonal.

15. The method of making a transducer which comprises subjecting a barium titanate ceramic to a polarizing voltage at the temperature at

which the crystals transform from the cubic to the tetragonal.

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