April 9, 1957 P. P. ZAPPONI 2,788,454

ELECTROMECHANICAL TRANSDUCER ELEMENT

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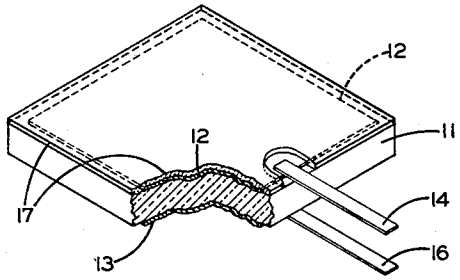


FIG. 1

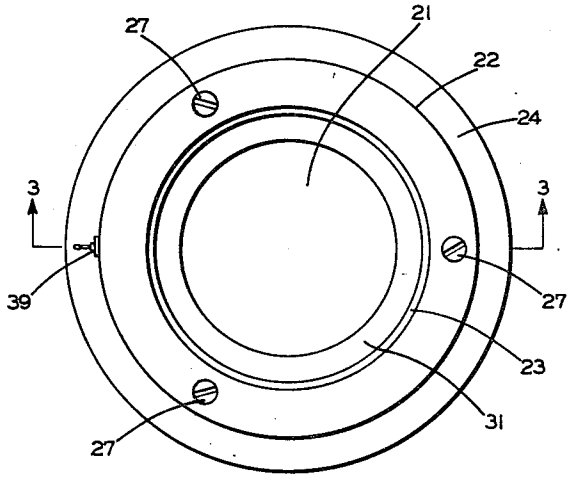


FIG. 2

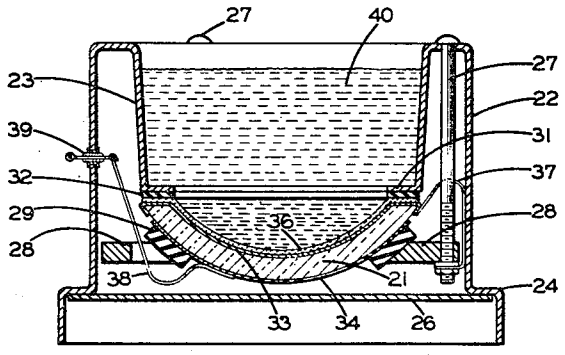


FIG. 3

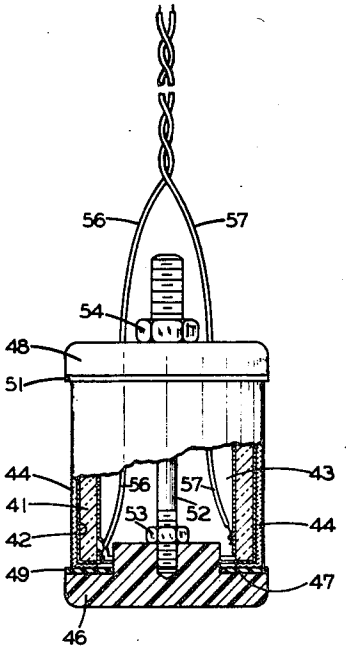


FIG. 4

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ELECTROMECHANICAL TRANSDUCER ELEMENT

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5 Claims. (Cl. 310—8.7)

This invention relates to electromechanical transducer elements and, more particularly, to such an element comprising a body of an electromechanically responsive dielectric material which has a refractory nature, that is, which can withstand elevated temperatures of at least several hundred degrees centigrade without fusing, disintegrating, decomposing, or suffering permanent deformation.

Optical reflecting surfaces have been made by depositing thin metallic films on the surfaces of glass bodies having a desired surface configuration, and it has been proposed to form over such metallic films a very thin deposit of a transparent oxidic material such as quartz to inhibit tarnishing of the metallic films. These metallic films ordinarily are of monomolecular dimensions, such as may be obtained by cathodic disintegration.

Different problems arise with dielectric electromechanical transducing materials, which for practical utilization of their electromechanical response properties must be provided with substantially thick coatings of electrically conductive material, these coatings serving as electrodes for translating the electrical charges associated with electrical fields in the dielectric transducing material. As used in this specification and in the appended claims, an electromechanically responsive dielectric material in the form of a solid body is a material having the property of responding to an electrostatic field in the body by developing a substantial and useful mechanical deformation. Conventional electrode coatings utilize metallic foil cemented to the surface of the body or alternatively a layer of a finely divided carbonaceous or metallic material held together and to the surface of the body by a cementing material.

A conductive electrode on such a surface of a hard, dielectric body may be subjected to strong disintegrating forces under the action of mechanical vibration during electromechanical transducing. Under certain conditions of use, especially when an electroded surface of the body is placed in direct contact with a fluid for translation of acoustic energy between the fluid and that surface, the electrode is subjected to corrosive forces of either a chemical or a mechanical nature or both. Furthermore, when the acoustic medium is a liquid, vibration of the surface during transducing may engender cavitation in the liquid, resulting in severe pitting or peeling of the electrode, and electroded surfaces apparently tend to induce undesirable cavitation, possibly due to the rough microscopic surface structure of the electrode. Difficulties also have been encountered in attempting to provide an insulating film over the electrode, especially when the electroded surface is to be exposed to sea water which is both corrosive and electrically conductive. Films of organic plastic materials have been used for external protection and insulation, but in some applications these films may prove to be deficient in their chemical, mechanical, or electrical integrity and strength.

Accordingly, it is an object of the present invention to provide a new and improved electromechanical transducer element, and process of making the same, which substantially avoid one or more of the limitations and disadvantages of the prior art elements and processes.

It is another object of the invention to provide a new and improved electromechanical transducer element having an electroded surface which has to a high degree most or all of the properties of mechanical strength and adhesion, electrical conductivity, resistance to chemical attack, and surface smoothness.

It is yet another object of the invention to provide an electro-acoustic transducer comprising a body of electromechanically responsive dielectric material having an electroded surface affording, when in acoustic contact with a fluid medium, new and improved properties of mechanical strength, chemical stability, acoustic energy translation, and, if desired, electrical insulation from the ambient medium.

It is still another object of the invention to provide, by a new and improved process which is dependable, inexpensive, and uncomplicated, a strong, highly conductive, yet adherent covering for a surface of a refractory dielectric transducer body.

In accordance with the invention, an electro-acoustic transducer comprises a body of electromechanically responsive refractory dielectric material, adherent, mutually opposed electrodes individually on opposite surfaces of the body, and an adherent vitreous coating over at least the major part of at least one of the electrodes. The transducer comprises additionally electrical leads for the electrodes and means for supporting the body with its vitreous coating disposed in acoustic contact with a liquid acoustic medium.

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 drawing,

Fig. 1 is a perspective view, partially cut away, of an electromechanical transducer element in accordance with the present invention and comprising a body, in the form of a plate or block rectangular in outline, of electromechanically responsive refractory dielectric material;

Fig. 2 is a plan view of an electro-acoustic transducer embodying the invention and comprising a dish-shaped transducer element;

Fig. 3 is a central sectional elevation of the same electro-acoustic transducer, taken along the plane identified as 3—3 in Fig. 2; and

Fig. 4 is a view in elevation, partially cut away, of an electro-acoustic transducer embodying the invention and comprising a tubular transducer element.

Referring now to Fig. 1, there is shown in perspective view, with one corner cut away, a rectangular plate 11 of electromechanically responsive refractory dielectric material. The dielectric material may be a piece cut from a single crystal of piezoelectric substance which can withstand elevated temperatures. Among such substances are crystalline quartz and a group of ferroelectric substances including barium titanate, lead titanate, and potassium niobate.

Preferably, however, the plate 11 has the form of a body of electromechanically responsive ceramic dielectric material, of which good examples are the titanate-type materials represented by barium titanate, with or without such additions as strontium titanate, calcium titanate, and lead titanate, and lead titanate itself. Potassium niobate also is useful in ceramic form as an electromechanically responsive material. These titanate-type materials in general are characterized by the perovskite crystal structure, which may be called a pseudo-cubic structure. In ceramic form the titanate-type materials re-

spond to an electric field by developing mechanical distortions proportional to the square of the field strength. However, under the influence of strong electric polarizing fields these ceramic materials exhibit very substantial linear electromechanical transducing properties for conversion of mechanical energy into electrical energy as well as for energy conversion in the reverse direction. An added advantage of many of these ceramic materials is that they retain a substantial remanent polarization, provided that the temperature does not exceed a critical value and that the electric signal fields applied thereto do not become excessively strong in the direction opposite to that of the remanent polarization.

Thus, in a preferred form of the electromechanical transducer element of the invention, the plate **11** of Fig. 1 is a body of dielectric material consisting essentially of barium titanate in ceramic form. It will be understood that this barium titanate ceramic may contain impurities of the order of one percent by weight, most of which are present for their fluxing action during the ceramic-firing operation.

When the process of producing an electromechanical transducer element in accordance with the present invention is carried out to produce an element such as that illustrated in Fig. 1, the process preferably comprises forming a body of titanate-type ceramic raw material, most commonly a barium titanate material, by a conventional forming procedure such as slip-casting to obtain a green ceramic body having approximately the shape of the plate **11**. The body then is subjected to ceramic-firing temperatures to produce the electromechanically responsive ceramic body or plate **11**; the maturing temperature for this ceramic-firing operation using barium titanate is in the neighborhood of 1350° C.

The next step in the process is the provision of adherent conductive electrodes on opposed faces of the body or plate **11**. As viewed in Fig. 1, the plate **11** has an upper electrode **12** and a lower electrode **13** on the opposed major faces of the plate. Preferably these electrodes are metallic, since they should be not only highly conductive but also capable of withstanding elevated temperatures. Certain metallic oxides such as silver oxide may be sufficiently conductive in oxidic form or may be applied as an oxide and reduced to metallic form by subsequent heating. Electrodes having metallic silver as their major constituent have been found to be desirable, and adherent electrodes of metallic silver bonded by a so-called ceramic flux have given excellent results. Since formulations for providing such conductive bonded coatings often have a paint-like consistency and appearance, they frequently are referred to as paints. Finely divided silver such as precipitated silver, or precipitated silver oxide, is the base material of a suitable paint. A suitable aqueous paint may contain several percent or more by weight of a so-called ceramic flux such as lead silicate, lead borate, or bismuth subnitrate, and polyvinyl alcohol may be added to stabilize the coating prior to baking.

The metallic paint containing the ceramic flux is applied to two opposed faces of the plate **11**. After drying the body is baked at a suitable temperature, which, more specifically, may be within the approximate range of 650–750° C., to soften or fire the ceramic flux and form the adherent metallic electrodes **12** and **13** from the metallic paint. Such electrode-forming materials containing oxidic fluxes which soften at baking temperatures of 675–710° C. have been used on ceramic barium titanate bodies with particular success.

It will be understood from the above that the provision of adherent conductive electrodes may be carried out using more or less conventional procedures. A paste or suspension of finely divided metallic particles with an inorganic or organic binder material may be applied and baked on. The refractory nature of the electromechanically responsive body, however, permits baking at elevated temperatures, so that the so-called paints containing ceramic fluxes may be used with excellent results.

The next step in the process involves the formation of an adherent vitreous coating over at least the major part of at least one of the electrodes. In the transducer element illustrated in Fig. 1, this vitreous coating is applied over almost the entire upper face of the plate **11**, including almost all of the upper electrode **12**. Preliminary to this operation, however, an upper lead **14** may be affixed conductively to the electrode **12** and a lower lead **16** affixed similarly to the electrode **13**. The vitreous coating **17** which is then formed is omitted from the region of the upper lead **14**, for example by masking during application of a material to be vitrified. In fact, when this is done, it often is preferable to form the vitreous coating first and affix the leads subsequently.

Ordinarily the vitreous coating **17** is of a siliceous material and is essentially glassy in nature. An entirely suitable vitreous coating has been formed by cutting a thin cover glass to the dimensions of the face of the plate **11**, followed by heating the glass to its softening point to fuse the cover glass to the electroded surface. It is preferred, however, to utilize glazing techniques which are more or less conventional in the ceramic art. In accordance with principles well understood in the art a fritted glaze composition may be chosen to have a desired fusion or maturing temperature and also to have a suitable fit on the refractory body, that is, to match rather closely the dimensional changes of the underlying body as the body is cooled from the maturing temperature of the glaze. In this way unduly high stresses are avoided during the cooling period after the glaze is fired. For application to a titanate-type ceramic material a low-fusing fritted glaze with rather high thermal expansion coefficient is indicated.

A composition which has been found to be suitable for application to an electroded barium titanate-type ceramic plate contains 95 parts by weight of a fritted glaze having a maturing temperature of 870–875° C., 5 parts of Florida china clay, and 60 parts of water. After ball milling for about one hour, this low-fusing fritted glaze material is applied over at least the major part of the electrode **12** by dipping or spraying. After the glaze is applied, the element is dried at 110° C., and then the body carrying the glaze material is fired to maturing temperature for one half hour. Variations of the fritted glaze composition permit variations in maturing temperature, but it is preferred to choose a composition which may be fired to a maturing temperature within the approximate range of 800–950° C. to form the adherent vitreous coating **17** on the electrode **12**. During firing the element may be supported on triangular fireclay blocks, followed by cooling over a period of several hours. In any case it is preferred that the adherent vitreous coating have a maturing temperature above 800° C. It is a remarkable fact that, in general, the metallic electrodes withstand these firing temperatures without chemical attack or loss of shape and adherence.

The electromechanically responsive transducer bodies suitable for use in accordance with the present invention may have a great variety of shapes and sizes. In some cases the thickness of such a body is dictated by the mechanical resonant properties of the body and may be as great as an inch or more between electrodes. In other cases strips of a ceramic material having considerable resiliency or flexibility may be desired, and the plate **11** may be of the order of only 0.010 inch in thickness. The adherent electrodes usually are about half a thousandth to a thousandth of an inch in thickness. The thickness of the vitreous coating is not critical, and it may be, for example, from several thousandths up to, say, 0.010 inch in thickness. The thicknesses of the electrodes and of the vitreous coatings as shown in Fig. 1 and in the other figures of the drawing have been exaggerated rather greatly for convenience of illustration.

Referring now to Figs. 2 and 3, there is illustrated an

electro-acoustic transducer comprising a tranducer element which might have the form of the element illustrated in Fig. 1. Preferably, however, the transducer element, as shown in Figs. 2 and 3, comprises a dish-shaped body 21 of a titanate-type ceramic material with the dished or concave surface arranged to face upward, as will appear hereinbelow. The body 21 has the shape of a portion of a hollow sphere, and a central chord across its upper edge at the concave side of the body subtends an angle of about 100° from the center of curvature. The rim of this spherical section is finished to lie in one plane for convenience of assembly of the body 21 into the complete transducer. A generally cylindrical housing 22 of sheet metal having an upper re-entrant portion 23 and a lower flanged portion 24 is provided with a bottom cover 26 welded beneath the lower flange of the housing. Bolts 27 pass between the outer portion of the housing 22 and the re-entrant portion 23 to support a metallic clamping ring 28. The inner edge of the ring 28 is beveled to match the curvature of the bottom surface of the body 21. A thick gasket 29 of resilient material is interposed between the inner beveled surface of the clamping ring and the lower face of the transducer element. When the bolts 27 are tightened, the transducer element is urged upwardly so that its planar edge surface presses against an inwardly extending flange 31 at the bottom of the re-entrant portion 23 of the housing. A resilient gasket ring 32 is interposed between the body 21 and the flange portion 31.

The dish-shaped body 21 is provided with adherent conductive electrodes 33 and 34 on its concave or upper and convex or lower surfaces repectively. It is convenient for the upper electrode 33 to extend over the planar edge surface of the body 21 and a short distance down along the lower surface, a margin being provided between the last-mentioned portion of the electrode 33 and the edge of the electrode 34. The electrodes 33 and 34 may be of any of the types discussed hereinabove as being suitable for the electrodes 12 and 13 in the Fig. 1 arrangement.

In the Fig. 3 arrangement, an adherent vitreous or glaze coating 36 is provided over one of the electrodes, specifically over the upper electrode 33. Preferably this vitreous coating is formed by applying a fritted glaze material, as described hereinabove in connection with the element illustrated in Fig. 1. As shown in Fig. 3, the glaze coating 36 extends over the planar edge of the body 21. Using the procedures described hereinabove, the vitreous coating 36 may be applied readily over the curved surfaces of the dish-shaped body.

Electrical leads are provided for the electrodes 33 and 34. A lead 37 is affixed conductively to the upper electrode 33 at a point where it extends slightly around the upper rim of the body 21 onto the lower surface of the body. The lead 37 is bound to one of the bolts 27 passing through the housing 22, since it is convenient for the upper electrode 33 to be maintained at ground potential. A lead 38 is affixed conductively to the lower electrode 34 and passes through a hole in the clamping ring 28 to a feed-through bushing 39 in the outer portion of the housing 22.

Means are provided in the electro-acoustic transducer for supporting the body 21 with its vitreous coating 36, covering the upper electrode 33, in acoustic contact with a liquid acoustic medium. Preferably only the vitreous coating of the body is permitted to be in acoustic contact with the liquid medium. The clamping arrangement, including the ring 28, gaskets 29 and 32, and bolts 27, which holds the body 21 against the inwardly extending flange 31 of the housing 22, constitutes, along with the housing itself, the means for supporting the body in acoustic contact with a liquid 40 which is held within the re-entrant portion 23 of the housing.

In the operation of the electro-acoustic transducer shown in Figs. 2 and 3, a source, not shown, of an oscillatory electrical potential is connected to the bushing 39 and

grounded to the housing 22 to provide electrical excitation, preferably at an ultrasonic frequency, across the electrodes 33 and 34 of the body 21. The body may have a thickness in its radial direction corresponding to a natural mechanical resonance at the ultrasonic frequency used. Mechanical distortions occurring at an ultrasonic frequency in the thickness direction of the body 21, produced by electromechanical transducing in the electromechanically responsive material of the body, are accompanied by corresponding motion or vibration at high amplitudes of the upper surface of the body in directions normal to that surface. This causes acoustic energy at the aforesaid ultrasonic frequency to be translated to the liquid 40 from the upper surface of the body 21 which carries the electrode 33 protected by the vitreous coating 36. Thus, acoustic waves are propagated through the liquid 40 with spherical wave fronts, causing a focusing effect of the acoustic energy at a focal region in the neighborhood of the center of curvature of the spherical body 21.

In this way extremely high concentrations or intensities of acoustic energy are obtained in the focal region below the upper surface of the liquid 40. This concentrated acoustic energy may be used to treat the liquid itself, or, alternatively, solid shapes may be subjected to intense ultrasonic acoustic irradiation by placing them in the body of liquid near the aforementioned focal region. The vitreous coating 36 has the property of withstanding the forces generated at the interface between the body 21 and the liquid 40 during long periods of irradiation at high energy levels without excessive deterioration, pitting, or peeling at the electroded surface covered by the vitreous coating. Furthermore, it has been observed that the intensity level of the acoustic energy which may be developed at this surface without causing cavitation in the liquid adjacent to the surface is considerably higher than is the case when the vitreous coating is not provided. This not only tends to avert cavitation, with the accompanying development of rather destructive forces, near the surface of the acoustic radiator, but also permits the acoustic radiation to reach the focal region in the liquid without the disturbances which impede the radiation at points where cavitation tends to occur.

Fig. 4 provides a view in elevation, with the bottom portion of the illustrated device cut away generally along a central plane, of a tubular electro-acoustic transducer which contains a transducing element comprising a tubular body 41, preferably of a titanate-type ceramic material. The body 41 has an outer electrode 42 which extends over the bottom edge of the tubular body. This electrode preferably is formed from a finely divided, heat-resistant conductive material, as disclosed in connection with the embodiment shown in the other figures of the drawing. The body 41 also has an inner electrode 43, a margin being provided near the bottom of the tube to maintain electrical separation between the electrodes 42 and 43. A similar insulated margin also is provided, of course, at the top edge of the body 41, which is not visible in Fig. 4. At the lower left hand edge of the tube, as viewed in Fig. 4, a tab extends from the lowermost portion of the outer electrode 42 a short distance upward along the inner surface of the tubular body, thus providing anchoring area for connecting a lead wire to the electrode 42, and the inner electrode 43 is cut back in the region of this tab to maintain insulating spacing between the electrodes.

A vitreous coating 44 is formed over the outer electrode 42 along the entire axial length of the tubular body 41. This coating 44 may be formed of similar materials, and using similar procedures, as the vitreous coatings 17 and 36 in the arrangements of Fig. 1 and of Figs. 2–3 respectively. The coating 44 conveniently may extend over the bottom and top edges of the body 41.

An arrangement is provided, as illustrated in Fig. 4, for disposing the tubular body 41, carrying the electrodes

42 and 43 and the outer vitreous coating 44, so that the coating 44, but no other part of the coated body, is in acoustic contact with a liquid medium such as sea water. For this purpose a bottom plug 46 having a flanged shoulder 47 is provided with a centrally located tapped hole in its upper portion. A similarly flanged top plug 48 also is provided having a central hole, not shown, therethrough. The plugs 46 and 48 may be of a phenolic-impregnated fabric material. The body 41 is pressed between the flanged shoulder 47 of the bottom plug and the similar shoulder portion of the top plug, with individual gasket rings 49 and 51 of a resilient material such as gum rubber being provided between the shoulders and the respective ends of the tube 41. A bolt 52 is threaded into the central hole in the bottom plug 46 and is prevented from turning by a lock nut 53. The upper end of the bolt 52 passes through the central hole in the top plug 48 and has an upper enlarged threaded portion which receives a nut 54. When the nut 54 is tightened, the plugs 46 and 48 are pulled together, thus compressing the gaskets 49 and 51 against the ends of the tubular body 41 to provide a liquid tight seal against entry of water to the interior of the tubular body.

A lead 56 is affixed conductively to the aforementioned tab of the outer electrode 42 at the lower left hand edge of the body 41 as viewed in Fig. 4. A similar lead 57 is affixed conductively to the inner electrode 43. The two leads 56 and 57 are insulated and pass through suitable holes in the top plug 48.

In operation, the electro-acoustic transducer illustrated in Fig. 4 may be suspended in sea water or in any other acoustic medium by its leads 56 and 57, so that only the outer electroded surface of the body 41, protected by the vitreous coating 44, is in contact with the liquid. The water-tight arrangement of the plugs 46 and 48 and associated components, along with the suspension arrangement just described, provides means for supporting the body 41 with only the vitreous coating 44 thereof in acoustic contact with the water. For this purpose a water-tight gland or cap, not shown, also may be fastened over the portion of the bolt 52 extending from the top plug 48, and over the leads 56 and 57 emerging from the plug, so as to seal completely the upper portion of the transducer assembly.

Operation of this electro-acoustic transducer device is quite similar to that of the transducer illustrated in Figs. 2 and 3. A source of electrical oscillations, not shown, is coupled to the leads 56 and 57 to impress electric potentials across the electrodes 42 and 43 and cause the transducer body 41 to change its effective diameter at a sonic or ultrasonic frequency. Thus the vibrating body radiates acoustic energy into the surrounding liquid. In this case, when the transducer is placed with its axis oriented vertically in the liquid, it will be evident that the radiation pattern in the liquid medium is omnidirectional in a horizontal plane. Conversely, it will be understood by those familiar with electro-acoustic devices that the Fig. 4 arrangement may be used as a microphone or receiver of acoustic waves in the liquid medium, the acoustic energy being coupled at the outer surface of the tubular body 41 to radial mechanical vibrations in the walls of the body, and these vibrations being transduced in the electromechanically responsive material of the body into electrical fields which appear as corresponding voltage variations across the leads 56 and 57. These voltage variations may be amplified, detected, and displayed by conventional apparatus, not shown, coupled to the leads.

While there have been described what at present are believed to be the preferred embodiments 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, and it is aimed, therefore, to cover in the appended claims all such changes and modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. An electro-acoustic transducer comprising: a body of electromechanically responsive refractory dielectric material, adherent, mutually opposed electrodes individually on opposite surfaces of said body, an adherent vitreous coating over at least a major part of one of said electrodes, electrical leads for said electrodes, and means for supporting said body with said vitreous coating in acoustic contact with a liquid acoustic medium.

2. An electro-acoustic transducer, comprising: a body of electromechanically responsive titanate-type ceramic dielectric material; adherent, mutually opposed electrodes on individual opposite surfaces of said body; an adherent vitreous coating over at least a major part of at least one of said electrodes; electrical leads for said electrodes; and means for supporting said body with said vitreous coating disposed in acoustic contact with a liquid medium.

3. An electro-acoustic transducer, comprising: a body of electromechanically responsive refractory dielectric material; adherent, mutually opposed electrodes of metallic silver bonded by a fired ceramic flux disposed individually on opposite surfaces of said body; an adherent vitreous coating of a predominantly siliceous material over one of said electrodes; electrical leads for said electrodes; and means for supporting said body with said vitreous coating disposed in acoustic contact with a liquid acoustic medium.

4. An electro-acoustic transducer, comprising: a body of electromechanically responsive ceramic dielectric material; adherent, mutually opposed metallic electrodes individually on opposite surfaces of said body; an adherent vitreous coating over at least a major part of one of said electrodes; circuit means, connected to said electrodes, for translating electrical energy transduced in said body; and means for supporting said body with said vitreous coating disposed in acoustic contact with a liquid acoustic medium for translating elastic-wave energy, transduced in said body, between said coating and said medium.

5. An electro-acoustic transducer arrangement, comprising: a body of electromechanically responsive refractory dielectric material; adherent, mutually opposed electrodes individually on opposite surfaces of said body; an adherent vitreous coating over at least a major part of one of said electrodes; means for supporting said body with said vitreous coating thereon disposed in acoustic contact with a liquid medium; and transducer-exciting means coupled to said electrodes for applying electrical potentials across said body to effect motions of said vitreous coating by electromechanical transducing in said body with resultant propagation from said coating of acoustic energy through said medium.

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