United States Patent

[11] **3,567,990**

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[45] Patented **Mar. 2, 1971**

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Continuation-in-part of application Ser. No. 679,075, Oct. 30, 1967, now abandoned.

[54] **ULTRASONIC IMAGING APPARATUS**
11 Claims, 4 Drawing Figs.

[52] **U.S. Cl.** **315/12,** 340/5, 313/68
[51] **Int. Cl.** **H01j 29/41**
[50] **Field of Search** ..... 315/12; 340/5 (I); 313/68

[56] **References Cited**

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ABSTRACT: An imaging receiving and writing tube includes a cylindrical evacuated envelope having an electron gun in one end wall and a wire mosaic in the other. A deflection apparatus is provided to control the electron stream sweep. Clips are mounted near the end having the wire mosaic, the clips being designed to hold any one of several piezoelectric crystal plates having different thicknesses. A collector electrode contained within the envelope cooperates with the mosaic and transducer to provide image signals. The device can operate as a display or writing device with the transducer removed. In another embodiment the selected crystal plate is temporarily and removably adhered with a thin coating of silicone compound or the like.

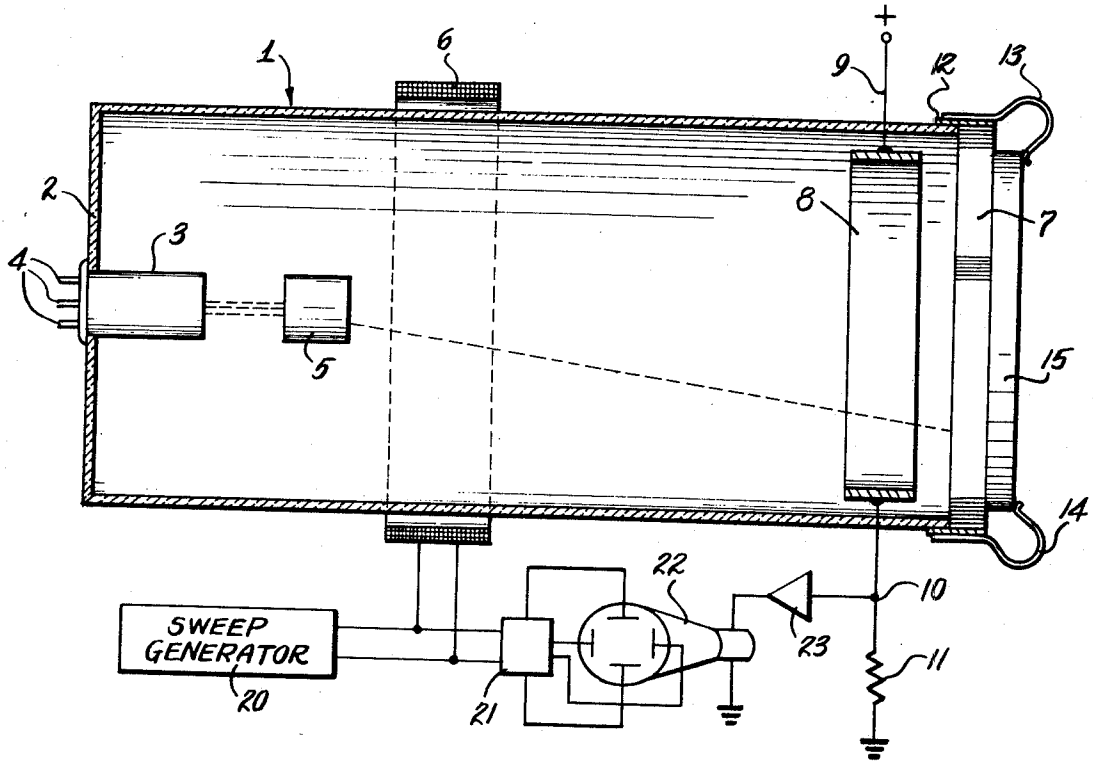


Fig. 1.

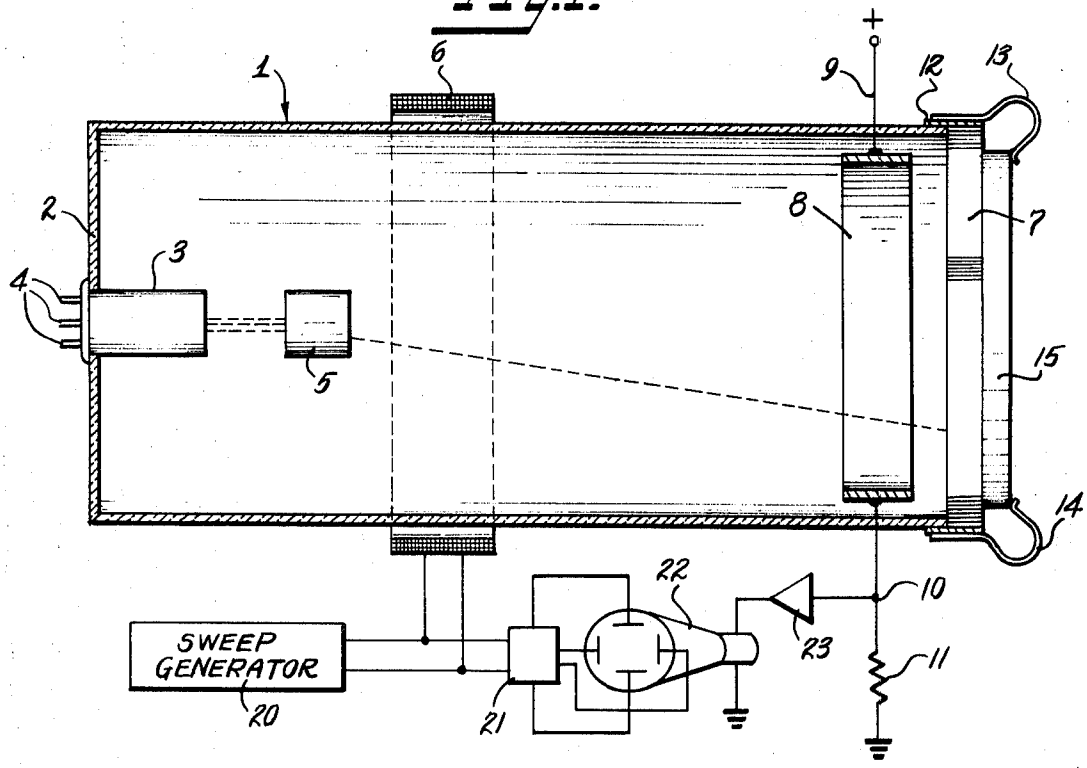
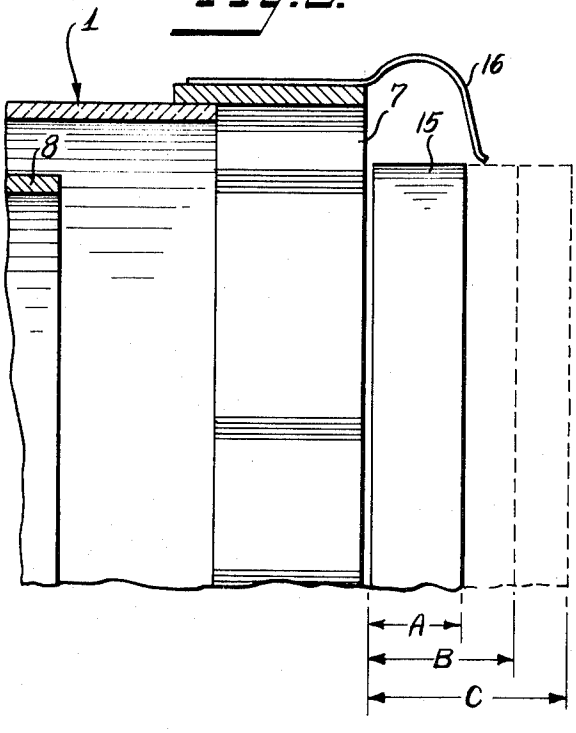


Fig. 3.



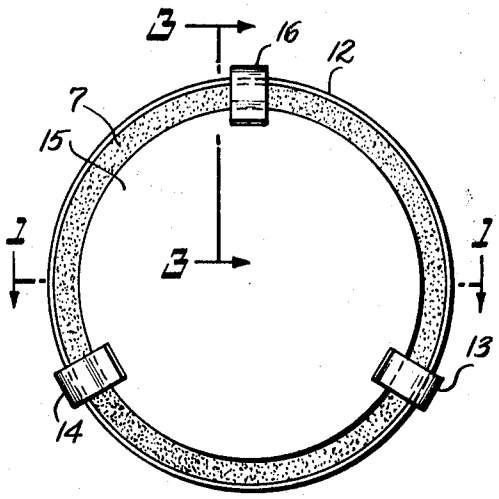


Fig. 2.

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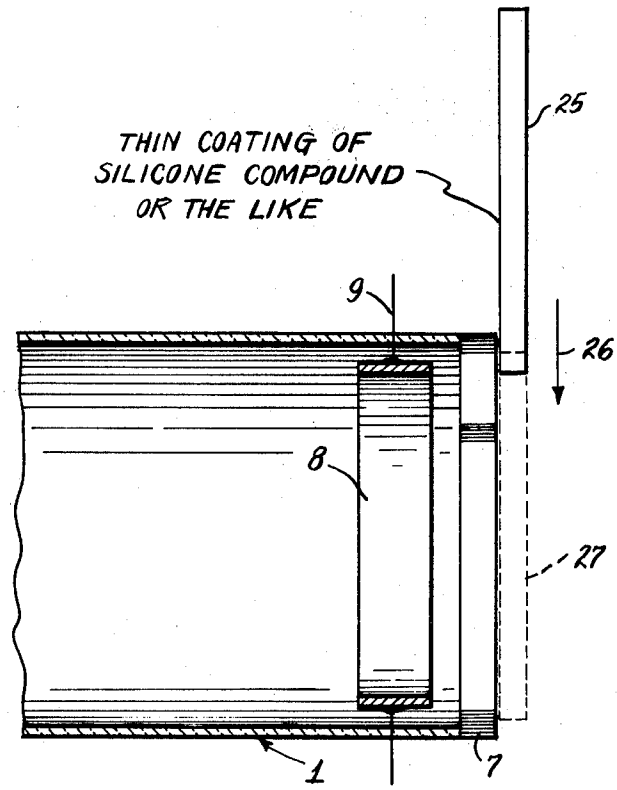


Fig. 4.

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ULTRASONIC IMAGING APPARATUS

This application is a continuation-in-part of copending U.S. Pat. application Ser. No. 679,075, filed Oct. 30, 1967, in the name of Roy R. Whymark, now abandoned. This invention relates to an apparatus for sensing or receiving pressure patterns and converting those patterns into electrical patterns and also for producing visual images of patterns.

The evolution of converting one form of energy signal to another has given rise to the development of several varieties of apparatus for converting electrical signals into electrical charge patterns which are convertible into visible patterns, and other devices which can produce electrical charge patterns representative of pressure patterns and sense the charge distribution to produce a permanent record or a visible picture or both.

One form of an apparatus of this kind includes an evacuated envelope, usually of glass, having a wire mosaic at one end, an electron gun at the other end, a collector device near the mosaic, and a stress-to-charge transducer adhered to, or forming a part of, the mosaic. The transducer generally consists of a plate of quartz, lead zirconate titanate (PZT) or the like, and has the property of responding to physical stress by producing, at least at one surface, a pattern of electrical charges which can be regarded as point charges. The surface exhibiting the charge pattern is mounted on a wire mosaic which comprises a plurality of extremely fine but rather short wires mounted or embedded in glass or a similar nonconductive material. The mosaic is in the form of a flat plate having a thickness of, for example, from 0.1 to 1.0 inch, with the wires all extending in the thickness direction. A discussion of mosaics of this type can be found in the Jul. 1963 issue of Electrical Design News in an article entitled "Microconductors in Glass," by Hildebrand and Farkas of Corning Glass Works, Corning, N.Y.

In operation, the charge distribution on the surface of the quartz or PZT plate induces a like charge pattern in the mosaic, the wires of the mosaic acting to reproduce the pattern on the interior surface of the mosaic. The electron gun produces a stream of electrons which is focused and swept across the interior surface by suitable conventional deflecting means. The electron stream interacts with the charge pattern to produce secondary emission surges which vary in intensity in proportion to the charge polarities and magnitudes. A collector electrode senses the variations and supplies a signal representative of charge characteristics. By simply coordinating the intensity variations with location of the swept electron stream, an oscilloscope or written record can be generated which has location and intensity characteristics like the pressure pattern.

One environment in which the apparatus can be used is in underwater imaging in which the end of the apparatus having the mosaic and transducer is immersed and ultrasonic energy reflected from or passed through an article is received at the transducer.

Devices of this type are made for specific applications and the structural and electrical characteristics are modified to suit the requirements of that application.

An object of the present invention is to provide an apparatus which has a removable and replaceable transducer plate to allow use of the same basic structure as either a receiver or as a writer.

Another object is to provide an imaging apparatus in which any one of a plurality of piezoelectric transducer portions can be attached to the basic envelope to render the apparatus usable at different frequencies, the frequencies being determined by transducer thicknesses.

A further object is to provide an apparatus having retaining means capable of holding any one of a plurality of transducers in operative position adjacent a mosaic.

Broadly, the apparatus of the invention includes an evacuated envelope containing an electron source and a collector electrode and having a wire mosaic in one end wall. Transducer retaining means is provided a the one end wall to hold a transducer plate adjacent the mosaic, if desired.

In order that the manner in which the foregoing and other objects are attained in accordance with the invention can be understood in detail, a particularly advantageous embodiment thereof will be described with reference to the accompanying drawings, which form a part of this specification, and wherein:

FIG. **1** is a plan view in section of one embodiment of the invention;

FIG. **2** is a front elevation of the apparatus of FIG. **1**;

FIG. **3** is a portion of a side elevation showing in greater detail the clip and transducer structure; and

FIG. **4** is a portion of a side elevation of another embodiment of the apparatus showing securing the transducer without clips.

Referring now to FIGS. **1** and **2**, it will be seen that the apparatus includes a cylindrical envelope **1** which can be of metal, glass or any other material capable of withstanding hydrostatic or high atmospheric pressure to which the apparatus can be subjected when used, for example, in underwater imaging at substantial depth. The envelope need not be circular but can be square or rectangular to suit the requirements of a particular application. One end of the cylinder is closed by an end wall **2** in which is mounted an electron gun **3** of conventional design similar to electron guns used in cathode ray tubes. Connectors **4** are provided to supply the necessary electrical energy to the electron gun. A suitable apparatus for forming the electrons emitted from gun **3** into a confined beam and for directing the beam includes a focusing apparatus indicated schematically at **5** and deflection means indicated schematically by a deflection coil **6**. It will be recognized that an electrostatic deflection system is equally suitable for the deflection means.

The other end of the cylinder is closed by a wire mosaic plate **7** which is sealed to the open end of cylinder **1** and which forms an integral part of the cylinder which is evacuated during or after assembly. A collector electrode **8** is mounted within the cylinder near mosaic plate **7** and is provided with suitable airtight connectors which extend through the walls of the cylinder. Electrode **8** is annular in shape and is of a diameter slightly less than the interior diameter of cylinder **1**. A conductor **9** connects the collector to a suitable DC bias source and a conductor **10** connects the electrode to one terminal of a resistor **11**, the other terminal of which is connected to ground. It will be recognized that voltage variation on electrode **8** will be developed across resistor **11** and will appear as voltage variations at conductor **10**.

The structure also includes an annular ring **12** which surrounds the mosaic plate and the end of cylinder **1** and which is adhered or otherwise firmly secured to the structure including the cylinder and mosaic plate. A plurality of resilient spring clips **13**, **14** and **16** are permanently attached to ring **12** and extend axially away from cylinder **1** and radially inwardly across the mosaic plate. Spring clips **13**, **14** and **16**, and other springs which can be mounted on ring **12** and circularly spaced around the end of the tube, are formed somewhat in the shape of a question mark with distal ends positioned to press inwardly toward the interior of cylinder **1** to retain a transducer plate **15** in close contact with the outer surface of mosaic plate **7**. Plate **15** is a piezoelectric body which has the property of responding to stress applied at its outer, exposed surface by producing an electric charge pattern on its inner surface (the surface adjacent the mosaic plate) which is similar in charge intensity variations to the physical stress variations at the outer surface. Materials which exhibit this property include quartz and lead zirconate titanate (PZT).

It has been found that plate **15** need not be a solid body but that it can be constructed from a plurality of small pieces. This is a distinct advantage in producing apparatus having a face diameter (or width, if rectangular) which is several inches across because of the unavailability of homogeneous piezoelectric bodies in suitable sizes. Thus, the plate can be made, for example, for a plurality of square pieces each having a dimension of 1 to 2 inches on a side. The small squares can either be assembled on the tube face in contact with the mosa-

ic or they can be preassembled into a unitary plate before combination with the remainder of the apparatus.

To envision the pattern appearing here, one might imagine a relief map of the pressure present at the exposed surface of the plate in which the longitude and latitude are equivalent to the X and Y dimensions of the plate surface. The hills and valleys of the map are then equivalent to high and low points of pressure. At the inner surface of the plate (adjacent the mosaic), a similar map could be constructed in which the hills and valleys are equivalent to magnitude of electrical charge.

The circuitry for the apparatus of FIG. **1** includes a conventional sweep generator **20** which produces a saw tooth voltage for causing the electron beam to sweep across the interior surface of mosaic **7** and to cause it to move stepwise downwardly to form a raster pattern similar to that of a television receiver. The output of generator **20** is connected to deflection means **6** and also to an interconnecting circuit **21** which provides the same deflection voltage to the deflection plates of a display device, shown in FIG. **1** as a cathode ray tube **22**. This interconnection provides that the sweep on cathode ray tube **22** will be directly correlated with the scanning sweep within tube **1**.

The intensity control of cathode ray tube **22** is provided by the output of an amplifier **23**, the input to which is the voltage developed across resistor **11**, this being the intensity variation voltage produced on the interior surface of mosaic **7** as a result of the charge distribution on plate **15**.

While it is believed that the operation of the apparatus should be clear from the above, a brief discussion of its operation will be given as used in underwater imaging. An object which is under water is illuminated by ultrasonic energy from a suitable source (not shown). Reflected energy, in the form of pressure waves having a pattern representative of the object, impinges on the exposed surface of plate **15**. Plate **15** produces, on its opposite surface, a charge pattern which is conducted to the interior of the tube by mosaic **7**. The charge pattern is examined by the electron beam as it is swept, line by line, across the mosaic, the secondary emission from the mosaic producing potential variations on electrode **8**. These appear as an output voltage at conductor **10** and are used to modulate the intensity of the beam in tube **22**. The sweep of tube **22** is synchronized with that of the beam from source **3**, thus producing a presentation on tube **22** very similar to the appearance of the illuminated submerged object.

It will be recognized by those skilled in the art that, as the sweep on CRT **22** is caused to pass across the interior of the tube face, the intensity of the light emitted by the phosphors on that face will be proportional to charge levels on the interior of mosaic **7** and that the charge distribution will therefore be reproduced as intensity variations on CRT **22**. It will further be recognized that tube **22** can be replaced by a strip chart or other recording device capable of producing a permanent record.

FIG. **3** shows in greater detail a portion of the apparatus shown in FIGS. **1** and **2**, specifically showing the portion of the tube at which the cylinder body **1**, the mosaic plate **7** and metal band **12** are attached and showing clip **16** secured to band **12**. Quartz plate **15** is shown in the position it would occupy as the plate is being put into position or being removed from its operative position with clip **16** extended outwardly to allow insertion or removal of the plate. As illustrated near the bottom of FIG. **3**, the thickness of plate **15** is identified by a dimension A. At this dimension the plate exhibits a specific oscillatory characteristic and operates most efficiently at a specific single frequency. A specific significant feature of this apparatus is that the plate can be removed and replaced by a plate having, for example, a thickness B or a thickness C, these other thicknesses being characterized by most efficient operation at different lower frequencies than a plate having dimension A. As will be recognized by those skilled in the art, different frequencies are suitable for different operational environments. For example, operation at a longer range requires a lower frequency and vice versa. The interchangeable feature of this apparatus allows the same basic structure to be used for various types of operations at various ranges and to various of resolution and accuracy. It is unnecessary with the apparatus of this invention to replace the entire tube, or to stock more than one tube in order to have at hand a multiple frequency capability.

It will also be recognized that the tube can be used as an electrostatic printer, such as that shown in U. S. Pat. No. **3**, 164,738, Fyler, in which a specially sensitized paper is passed across the face of the tube while an intensity modulated beam is caused to sweep across the interior surface of mosaic **7**. Thus, the same tube can perform the initial function of a writing or transmitting function merely by removal of the quartz plate and the addition of means for feeding the paper.

FIG. **4** shows an additional embodiment of the apparatus which is characterized by even greater simplicity in that the mechanical clips are not used. In FIG. **4** the evacuated envelope **1** and mosaic are constructed as previously described. A piezoelectric transducer **25** is attached to the mosaic by first spreading a thin coating of a substance such as a silicone compound on one surface of the transducer, placing the transducer against one side of the mosaic with the coated side parallel to the outer face of the mosaic in the position shown by solid lines in FIG. **4**, and then sliding the transducer across the mosaic in the direction of arrow **26** until it reaches the desired position as shown by the dotted line FIG., **27**.

The adhering substance such as a silicone compound, mentioned above, should have several characteristics, as follows: it should be insoluble in water, since the apparatus has primary utility as an underwater imaging device; it should not harden or become a permanent adhesive over a period of time, since a primary objective is to maintain replaceability of the transducer; it should be smooth and homogeneous in consistency and be capable of even, this distribution on the transducer surface; and it must be electrically nonconductive so as to not destroy the electrical charge pattern on the transducer face to which it is applied. It will be apparent that the term "adhering substance," as used herein, is meant to convey the concept of temporary adherence only and not permanent adherence as would result from the use of an epoxy resin, ketone glue or the like.

A silicone compound which has proved suitable for this purpose is DC4 Silicon Compound manufactured by Dow Corning Corporation, Midland, Michigan. Another substance which is suitable for the purpose is common petroleum jelly.

It should be emphasized that the method described above for temporarily adhering the transducer to the mosaic can be accomplished in a few seconds and that it can be done while the entire structure is underwater, if desired. Thus, if an imaging operation is underway and if it appears that a different frequency could be used with better results, the illuminating source frequency can be changed and then the transducer on the face of the imaging tube can be replaced with one cut to the new frequency without disturbing or altering the various pieces of equipment used in the operation. One need only reach in, slip off the old transducer, spread the new one with silicone grease, slip on the new one, and proceed with the task at hand.

The thickness of the coating of the substance which can be used without deleterious effect on the operation depends to some extent on the frequency of operation and on the maximum resolution obtainable, which depends, at least partly on frequency. For example, at an operating frequency of 10 MHZ the resolution limit is about 10 mils (0.010 inch) with a quartz transducer thickness of 10 mils. For good results, there should be five wires in the mosaic within that 10 mil resolution distance so that the wires would be spaced about 2 mils apart. With a coating thickness of 1 mil or less, the coating has not detectable effect on the operation of the system.

As the frequency goes down and the resolution limit goes up, the thickness of the coating can increase without effect on the system operation. Conductivity through the coating is, of course, not important since it is electrostatic charge that is being sampled and detected through the coating and mosaic.

A feature of this apparatus which cannot be readily illustrated in the drawings is based upon the fact that the wire mosaic is a structurally very strong member. The prior art includes devices in which an evacuated cylindrical envelope is sealed at one end with a quartz plate, no wire mosaic being used. These devices have been used in a somewhat similar manner, but have not been usable for underwater imaging at any significant depth because of the great hydrostatic pressures which are encountered and which tend to fracture the quartz plate. With the wire mosaic plate attached to the tube, the sensitive end of the tube can be made very large, thereby providing a sensitive surface capable of receiving ultrasonic energy over an area much more suitable for such work. The diameter can be easily on the order of 12 to 20 inches.

While one advantageous embodiment has been chosen to illustrate the invention, it will be understood by those skilled in the art that various changes and modifications can be made therein without departing from the scope of the invention as defined in the appended claims.

I claim:

1. An apparatus for converting pressure patterns into electrical signals representative of the pattern comprising the combination of:
- an evacuated envelope;
- an electron source mounted in said envelope;
- means for forming electrons emanating from said source into a stream and for controlling the direction of the stream;
- a wire mosaic plate mounted in one wall of said envelope with one active surface exposed;
- a plurality of piezoelectric transducers each having one major surface at which an electrical charge pattern appears in response to a physical stress pattern imposed on a second major surface; and
- retaining means mounted on the structure including said envelope and said wire mosaic plate for removably holding a selected one of said transducers adjacent said mosaic plate with said one major surface in contact with the exposed surface of said mosaic plate;
- said mosaic plate being operative to transfer charge patterns appearing on said one major surface of said transducer to the interior of said envelope for investigation with said electron stream.

2. An apparatus according to claim 1 and further comprising:
- a collector electrode mounted within said envelope to detect changes in electron flow within said envelope due to a charge pattern on said mosaic plate.

3. Apparatus according to claim 1 wherein said mosaic plate comprises:
- a glass body in the shape of a cylinder having two major surfaces perpendicular to the cylinder axis; and
- a large plurality of small diameter wires embedded in said glass body;
- said wires extending parallel to each other and to said cylinder axis between said major surfaces.

4. Apparatus according to claim 1 wherein:
- said envelope is in the form of a right circular cylinder having a circular end wall and an open end;
- said electron source being mounted in said end wall;
- said mosaic plate is circular and is mounted at the open end of said envelope to form a second end wall; and
- said retaining means is mounted on said envelope near said open end and extends axially beyond said mosaic and radially inwardly across said mosaic in position to retain said transducer.

5. Apparatus according to claim 1 wherein:
- said retaining means comprises:
- a plurality of resilient clips secured to the structure including said envelope and said mosaic plate;
- said clips extending across said exposed surface of said mosaic plate in position to grip and hold a transducer placed in contiguous relationship with said exposed surface.

6. Apparatus according to claim 1 wherein:
- said plurality of transducers comprises:
- a selection of cylindrical bodies of piezoelectric material;
- each said body having first and second major parallel surfaces axially separated by the body thickness;
- said bodies being of different thicknesses to provide a selection of primary operating frequencies.

7 An apparatus for converting pressure patterns into electrical signals representative of the pattern comprising the combination of;
- an evacuated envelope;
- an electron source mounted in said envelope;
- means for forming electrons emanating from said source into a stream and for controlling the direction of the stream;
- a wire mosaic plate mounted in one wall of said envelope with one active surface exposed interiorly of said envelope and a second active surface exposed exteriorly of said envelope;
- a plurality of piezoelectric transducers each having one major surface at which an electrical charge pattern appears in response to a physical stress pattern imposed on a second major surface;
- retaining means mounted on the structure including said envelope and said wire mosaic plate for removably holding a selected on eof said transducers adjacent said mosaic plate with said one major surface in contact with the exteriorly expose surface of said mosaic plate;
- said mosaic plate being operative to transfer charge patterns appearing on said one major
- surface of said transducer to the interior of said envelope for investigation with said electron stream;
- a collector electrode mounted within said envelope near said interiorly exposed surface of said mosaic plate;
- first circuit means connected to said means for controlling the direction of the electron stream for causing said stream to scan said mosaic in a predetermined pattern;
- second circuit means connected to said collector electrode for detecting voltage variations produced therein and for developing a signal representative of intensity variations representative of physical stress variations at said transducer; and
- third circuit means connected to said first and second circuit means for correlating location and intensity signals to produce a pattern equivalent to said stress pattern.

8. An apparatus for converting pressure patterns into electrical signals representative of the pattern comprising the combination of:
- an evacuated envelope;
- an electron source mounted in said envelope;
- means for forming electrons emanating from said source into a stream and for controlling the direction of the stream;
- a wire mosaic plate mounted in one wall of said envelope with one active surface exposed;
- a plurality of piezoelectric transducers each having one major surface at which an electrical charge pattern appears in response to a physical stress pattern imposed on a second major surface; and
- means for removably holding a selected one of said transducers adjacent said mosaic plate with said one major surface in contact with the exposed surface of said plate;
- said mosaic plate being operative to transfer charge patterns appearing on said on em one major surface of said transducer to the interior of said envelope for investigation with said electron stream.

9. Apparatus according to claim 8 wherein said means for removably holding a selected on eof said transducers comprises:
- a thin coating of a spreadable, water insoluble, electrically nonconductive nonhardening substance having a smooth homogeneous texture between said selected one of said transducers and said mosaic plate.

10. An apparatus according to claim 9 wherein said spreadable substance is petroleum jelly.

11. A method of temporarily and removably adhering a flat surface of a piezoelectric transducer to a flat surface of a wire mosaic plate comprising:

coating one of the flat surfaces with a thin layer of a spreadable, water insoluble, electrically nonconductive, nonhardening substance having a smooth homogeneous texture;

placing the flat surface of the transducer parallel to and in slightly overlapping contacting relationship with the flat surface of the mosaic plate; and

sliding the transducer across the mosaic plate in a direction to increase the overlap until the entire flat surface of the transducer is contiguous with the flat surface of the mosaic plate.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,567,990 Dated March 2, 1971

Inventor(s) Roy R. Whymark

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Col. 1, line 74, "a" first occurrence should read --at-- Col. 2, line 73, "for" second occurrence should read --from-- Col. 4, line 2, after "various" third occurrence should be inserted --degrees--; line 18, after "mosaic" should be inse --7--; line 34, "this" should read --thin--; line 69, "not" should read --no--; Col. 6, line 25, "on eof" should read --one of--; line 27, "expose" should read --exposed--; line before "plate" should be inserted --mosaic--; line 63, "on e should be deleted; line 67, "on eof" should read --one of--.

Signed and sealed this 10th day of August 1971.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

WILLIAM E. SCHUYLER, JR.
Commissioner of Patents