

Nov. 15, 1938.

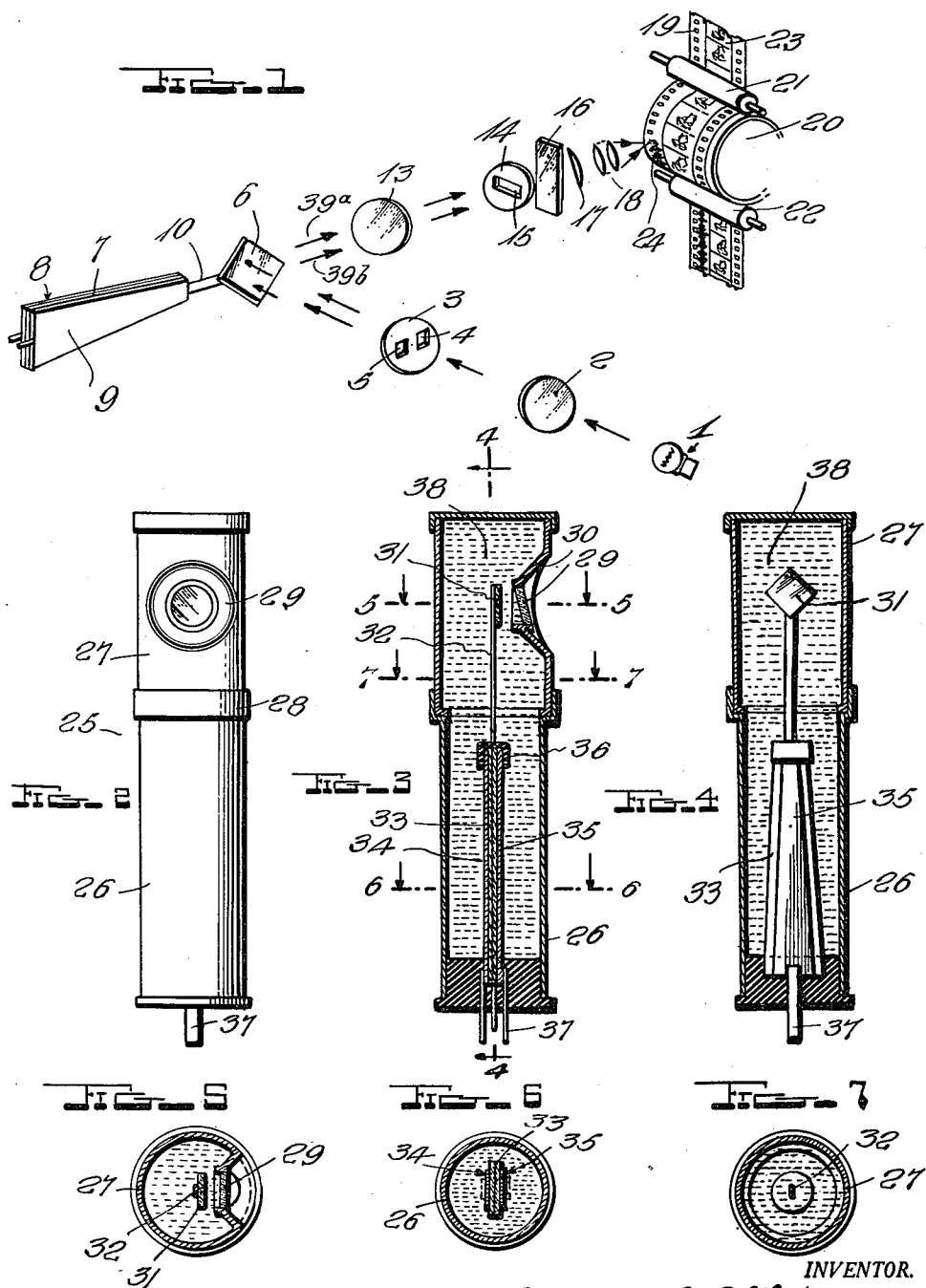
S. C. WHITMAN

2,137,188

PIEZOELECTRIC CRYSTAL MIRROR SYSTEM FOR SOUND RECORDING

Filed Nov. 20, 1937

7 Sheets-Sheet 1



INVENTOR.
Stewart C. Whitman,
BY
Jacobi & Jacobi ATTORNEYS.

Nov. 15, 1938.

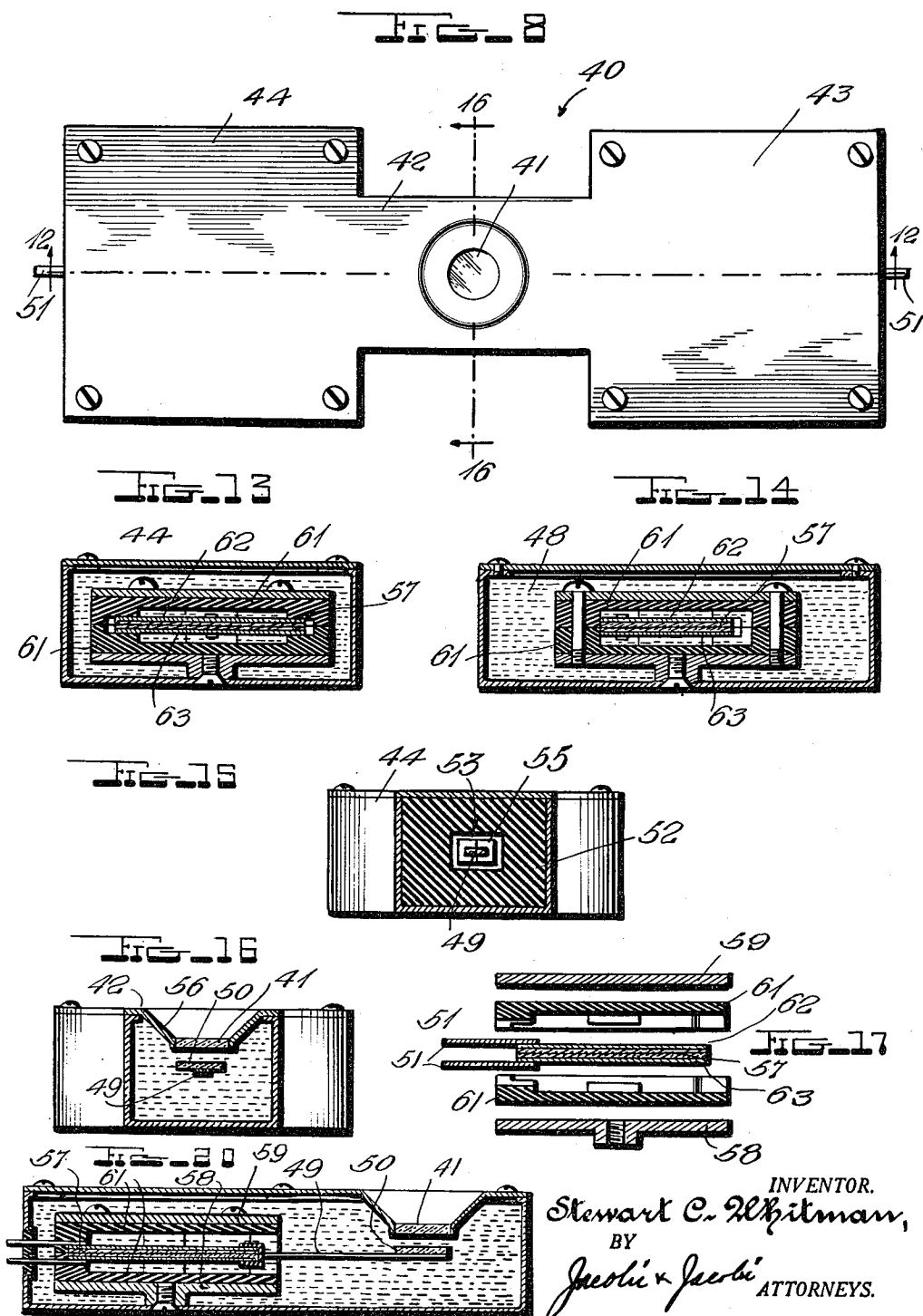
S. C. WHITMAN

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PIEZOELECTRIC CRYSTAL MIRROR SYSTEM FOR SOUND RECORDING

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7 Sheets-Sheet 2



INVENTOR.
Stewart C. Whitman,
BY
Jacobi & Jacobi
ATTORNEYS.

Nov. 15, 1938.

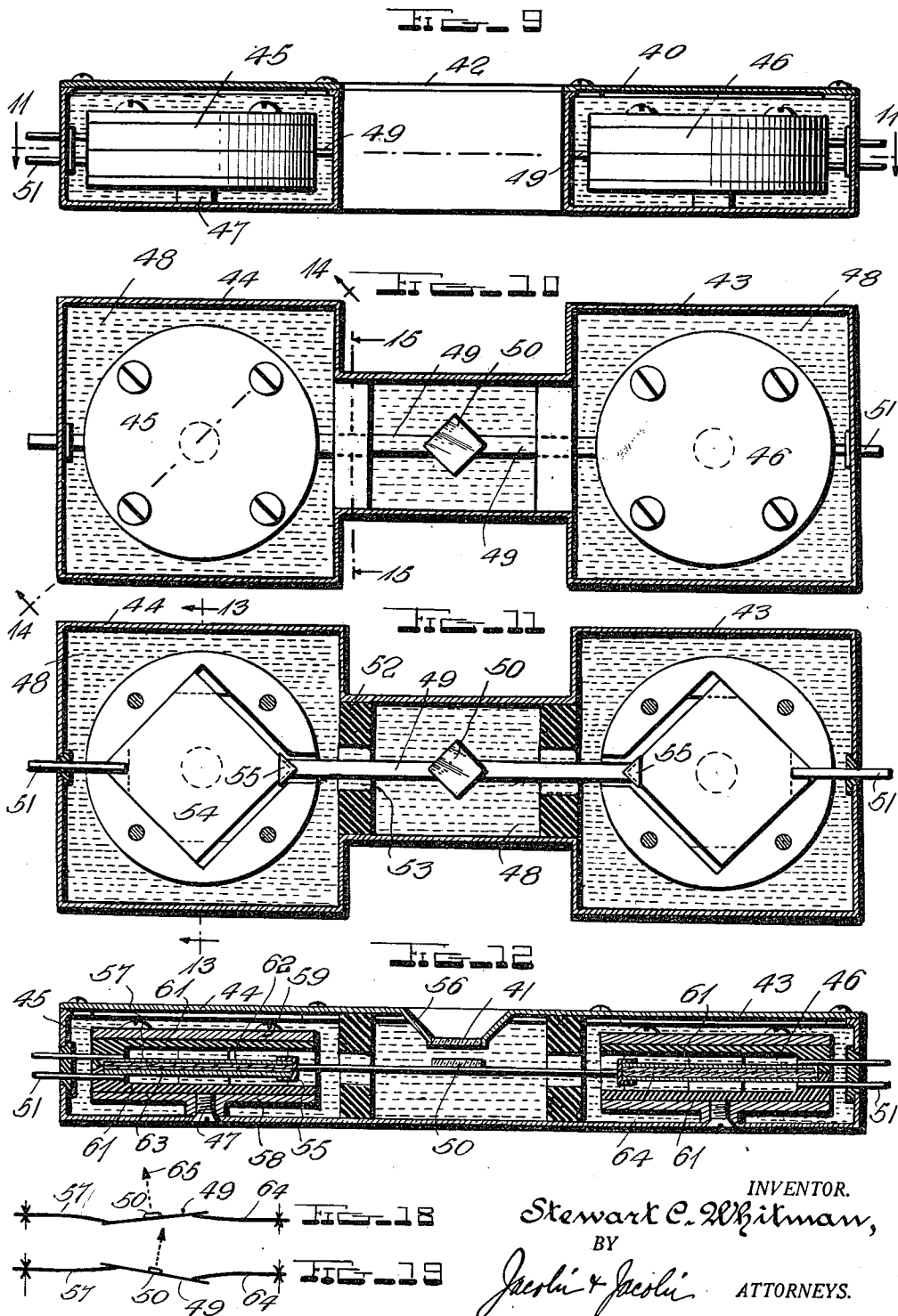
S. C. WHITMAN

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PIEZOELECTRIC CRYSTAL MIRROR SYSTEM FOR SOUND RECORDING

Filed Nov. 20, 1937

7 Sheets-Sheet 3



INVENTOR.
Stewart C. Whitman,

BY

Jacobi & Jacobi ATTORNEYS.

Nov. 15, 1938.

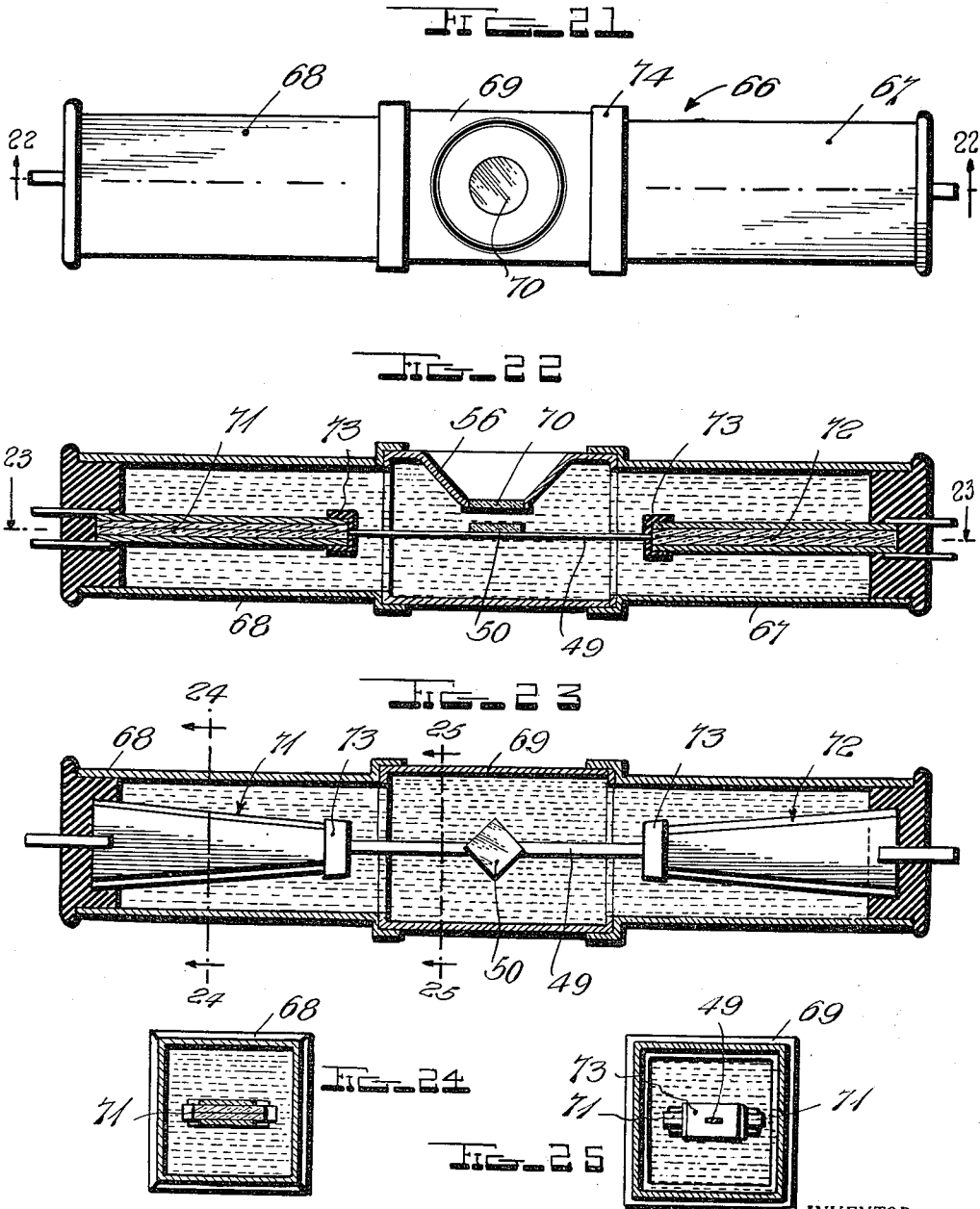
S. C. WHITMAN

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PIEZOELECTRIC CRYSTAL MIRROR SYSTEM FOR SOUND RECORDING

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7 Sheets-Sheet 4



INVENTOR.
Stewart C. Whitman,
BY *Joseph Jacoby*
ATTORNEYS.

Nov. 15, 1938.

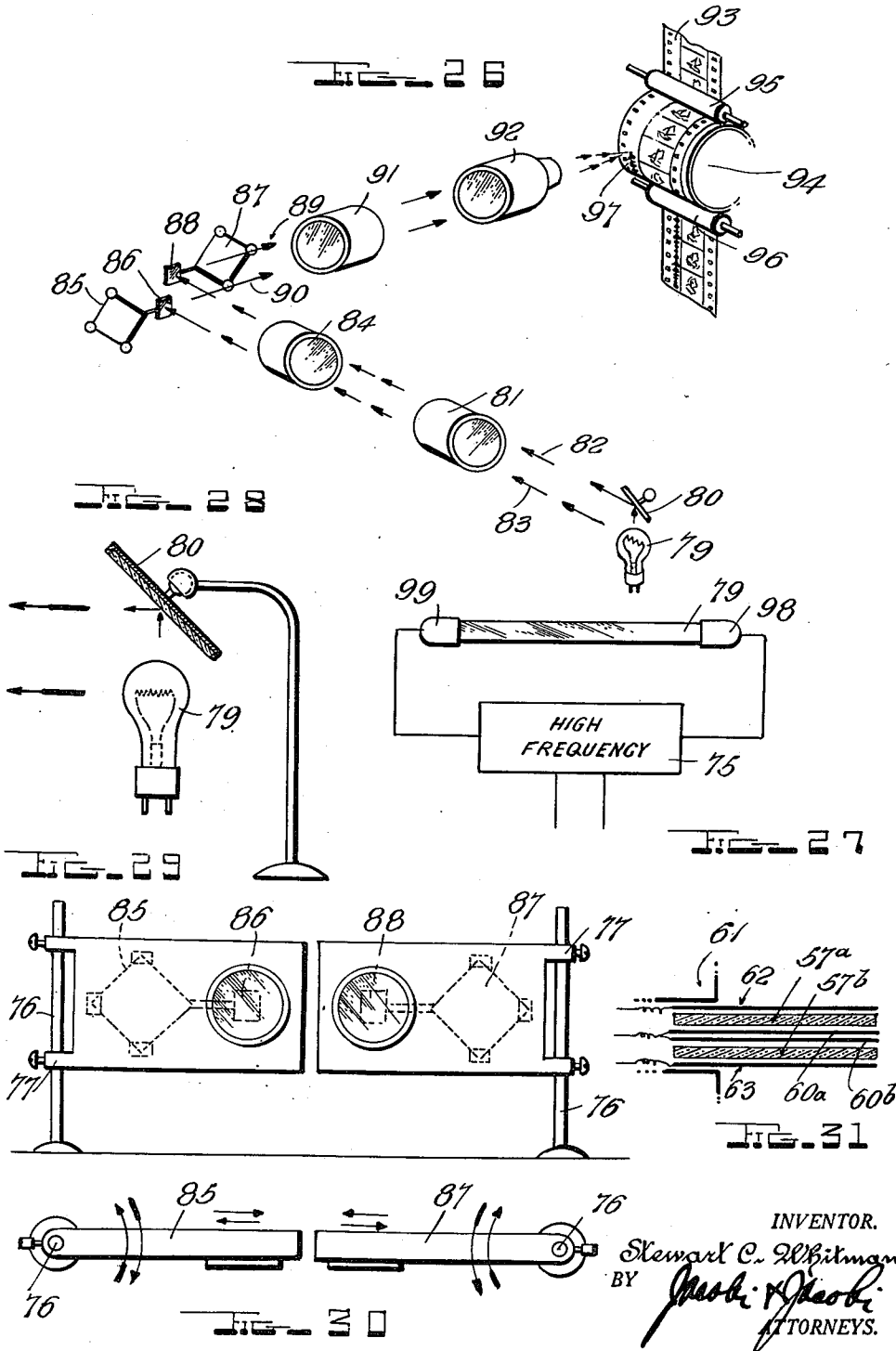
S. C. WHITMAN

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PIEZOELECTRIC CRYSTAL MIRROR SYSTEM FOR SOUND RECORDING

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7 Sheets-Sheet 5



Nov. 15, 1938.

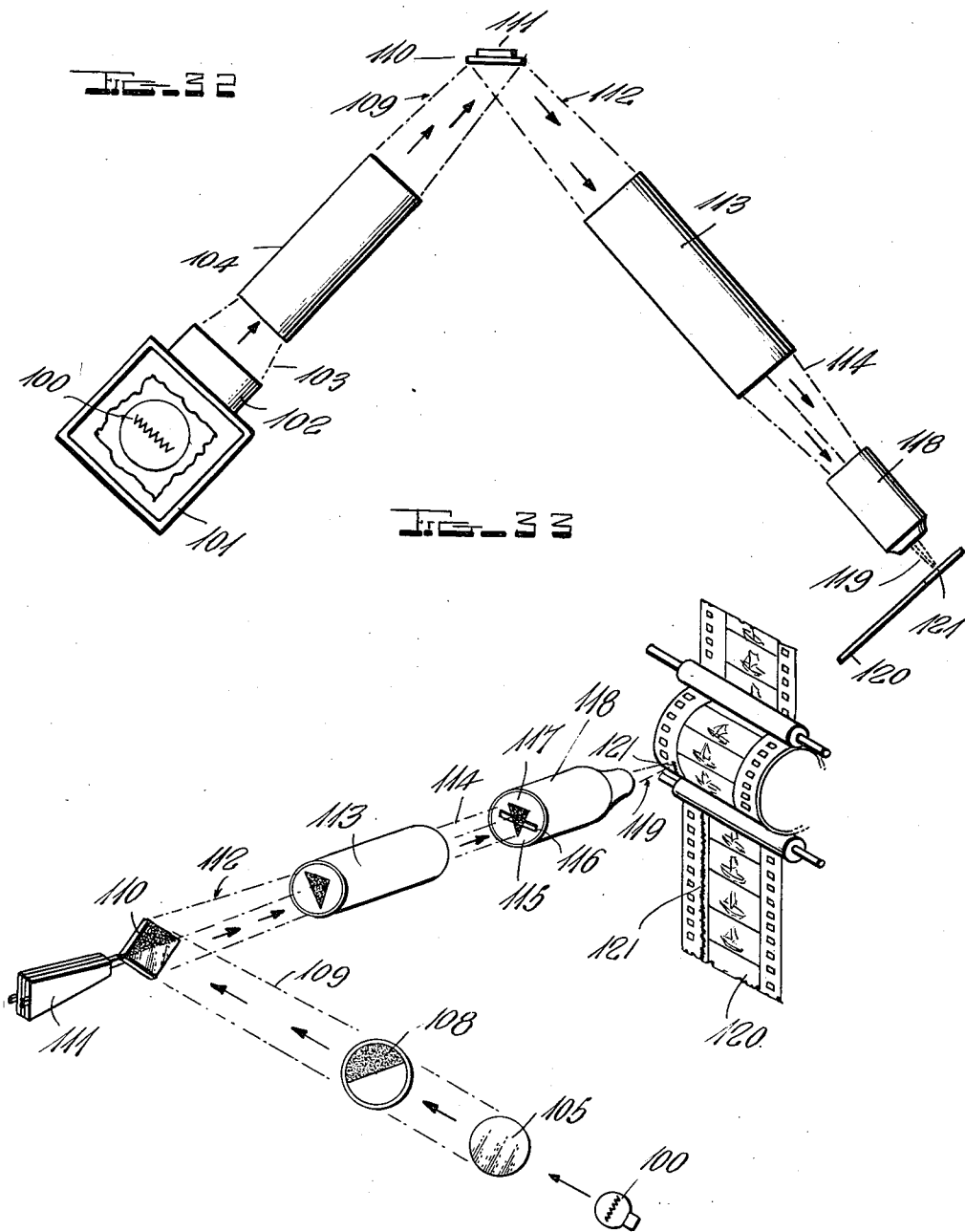
S. C. WHITMAN

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PIEZOELECTRIC CRYSTAL MIRROR SYSTEM FOR SOUND RECORDING

Filed Nov. 20, 1937

7 Sheets-Sheet 6



INVENTOR.
Stewart C. Whitman
BY *Robert Jacob*
ATTORNEYS.

Nov. 15, 1938.

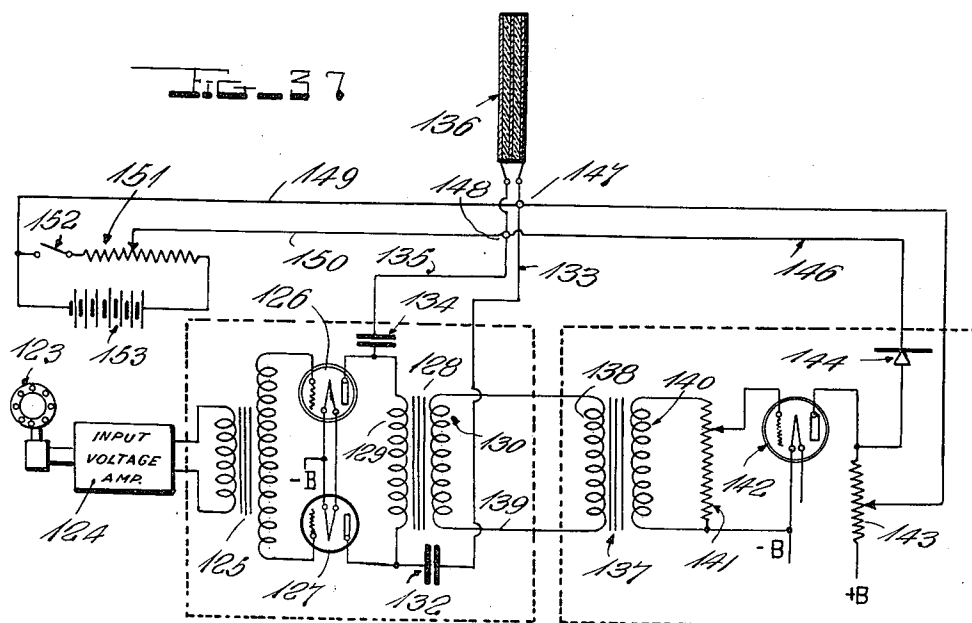
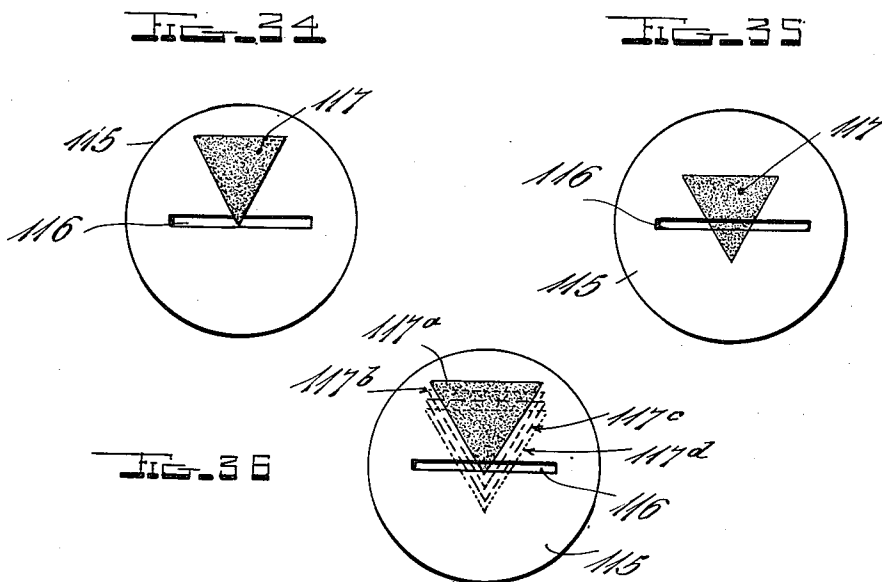
S. C. WHITMAN

2,137,188

PIEZOELECTRIC CRYSTAL MIRROR SYSTEM FOR SOUND RECORDING

Filed Nov. 20, 1937

7 Sheets-Sheet 7



INVENTOR.
Stewart C. Whitman,
BY *Jack J. Jack*
ATTORNEYS.

UNITED STATES PATENT OFFICE

2,137,188

PIEZOELECTRIC CRYSTAL MIRROR SYSTEM
FOR SOUND RECORDING

Stewart C. Whitman, New York, N. Y.

Application November 20, 1937, Serial No. 175,735

12 Claims. (Cl. 179—100.3)

My invention relates to the recording of sound on film and more especially to a system employing a piezoelectric crystal for impressing sound frequencies on light beams.

5 A purpose of my invention is to provide a system which will vary a light beam at sound frequencies and which has minimum inertia of the moving parts.

10 Another object of my invention is to provide a sound recording system using piezoelectric crystal elements arranged to act as the "bender" type as well as the "twister" type of crystal elements.

15 A further object is to provide a sound recording system employing a pair of piezoelectric crystals arranged to cooperate to produce a maximum mirror deflection.

20 Still another object is to provide a system for varying a light beam at sound frequencies while avoiding the employment of the electromagnetic effect of a current actuating an armature element in a magnetic field.

25 Yet another object is to provide a sound recording system employing two separate modulated light beams giving a sound track modulated on both sides with double the sound value and making a duplicate sound unit and record available in case one unit fails.

30 Another object is to provide a piezoelectric crystal sound recording system wherein the crystal element is mounted in a casing filled with mineral oil for damping the crystal vibrations.

35 A still further object is to provide a sound recording system wherein the piezoelectric crystal element is mounted behind a window inclined obliquely transverse to the reflected beam path.

40 Other purposes will be in part obvious and in part pointed out hereinafter. The usual electromagnetic oscillograph heretofore employed in the art possesses relatively large inertia and produces distortion, which is avoided by my arrangement.

45 I provide a piezoelectric crystal or other electromechanical vibratile element carrying a mirror attached to a point of the crystal element where such element vibrates with considerable amplitude under the action of an applied voltage of audio frequency. One or more beams from a source of light are incident upon such mirror, and the beam or beams are thereby reflected
50 through a suitable optical system upon the sound track of a sensitive film.

In one form of my invention I employ a single crystal element of the "twister" or torsion type, and in another form I employ a pair of "twisters."

55 In another modification of my invention I em-

ploy a single crystal element of the "bender" type, and in a further modification I employ a pair of "bender" type crystal elements with one or with two separate mirrors. In the forms wherein a pair of crystal elements displace a single mirror, I provide a thin metallic ribbon which carries the mirror and which is attached to the crystal elements.

My crystal elements may consist of a single slab or plate of piezoelectric crystal. Various crystal-
10 line substances are known in the art to possess piezoelectric properties, but I prefer to employ Rochelle salt crystals in plates cut from the crystal as it grows in nature in orientation to the crystallographic axes as is known in the art to produce the desired type of mechanical reaction to applied voltage, or vice versa. In the "twister" type of crystal, a trapezoidal shape of crystal gives particularly good performance especially as to
15 range of frequency response.

20 While I may employ a single slab or plate of crystal for each crystal element, better results may usually be obtained by superposing in mutually restrained relation two crystal plates so cut and oriented when mounted that under the action of an applied voltage one crystal plate tends to elongate in a given direction when the other crystal plate is tending to shorten in that direction, which produces an intensified twisting or bending movement of the crystal assembly, depending
25 on the way the crystal plates are cut, and the way they are mounted and restrained. What are known in the art as 45° X cut plates are suitable for the purpose, and should be assembled in pairs and mounted as is known in the art to produce the "twisters" and "benders." The voltage may be applied to such a pair of superposed mutually restrained crystal plates by electrodes positioned on the outer free faces of the assembled crystal unit, or in addition to such outer
30 electrodes there may also be provided an intermediate electrode of thin metallic foil positioned between the abutting faces of the crystals.

A crystal element fixedly mounted at one end and when electrically actuated rotatably or torsionally displacing its free end is known as a "twister", and is usually relatively long and narrow. A crystal element which is so cut and mounted that when electrically actuated it tends to bend in a direction perpendicular to the faces, is called a "bender", and is usually restrained along a number of its edges or at a number of points, while leaving at least one point and adjacent edge portions freely movable. A convenient
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form of bender is square. Other shapes of crystals may be used for either type.

My invention will be better understood by reference to the following specification and accompanying drawings wherein like reference characters designate like parts and wherein

Figure 1 shows a schematic view of the general assembly of the elements of my invention employing a "twister" type of crystal element;

Figure 2 is a front elevation of the casing of the piezoelectric crystal mirror unit;

Figure 3 is a central vertical longitudinal sectional view thereof;

Figure 4 is a transverse vertical section taken on the line 4—4 of Figure 3;

Figure 5 is a horizontal sectional view taken on the line 5—5 of Figure 4;

Figure 6 is a similar view taken on the line 6—6 of Figure 3;

Figure 7 is a horizontal sectional view taken on the line 7—7 of Figure 3;

Figure 8 is a top plan view of a form of my invention employing a pair of "bender" type crystal elements which cooperate to displace a mirror;

Figure 9 is a front elevation with parts broken away and in section of the arrangement of Figure 8;

Figure 10 is a horizontal sectional view of the arrangement of Figure 8 showing the details of the ribbon carrying the mirror;

Figure 11 is a horizontal section taken on the line 11—11 of Figure 9;

Figure 12 is a central vertical longitudinal sectional view taken on the line 12—12 of Figure 8 and showing the pair of "bender" crystal elements and the ribbon carrying the mirror;

Figure 13 is a transverse vertical section taken on the line 13—13 of Figure 11, showing a detail of the mounting of the "bender" type of crystal element;

Figure 14 is a transverse vertical section taken on the line 14—14 of Figure 10;

Figure 15 is a transverse vertical section taken on the line 15—15 of Figure 10;

Figure 16 is a transverse vertical section taken on the line 16—16 of Figure 8;

Figure 17 is an exploded view of the "bender" crystal element of Figure 14 showing the crystal element and adjacent parts separated and in juxtaposition;

Figures 18 and 19 are schematic views illustrating the principle of the action of a pair of "bender" crystal elements in displacing the mirror carried on the ribbon;

Figure 20 is a vertical sectional view of a single crystal element unit of the "bender" type;

Figure 21 is a front elevation of the casing of a modification of my invention employing a pair of "twister" type crystal elements which cooperate to displace a ribbon carrying the mirror;

Figure 22 is a central vertical longitudinal sectional view taken on the line 22—22 of Figure 21 showing the twister crystal elements and the ribbon;

Figure 23 is a horizontal sectional view taken on the line 23—23 of Figure 22, showing the trapezoidal "twister" crystal elements;

Figure 24 is a transverse vertical section taken on the line 24—24 of Figure 23;

Figure 25 is a transverse section taken on the line 25—25 of Figure 23;

Figure 26 is a schematic view of the assembly of a modification of my invention employing two single "bender" crystal elements each with its own

mirror which produce two separate modulated beams of light;

Figure 27 is a schematic detail view of a high-frequency exciter lamp for the arrangement of Figure 26;

Figure 28 is a detail of the exciter lamp with its mirror in the arrangement of Figure 26;

Figure 29 is a detailed view of the structure for swingably mounting the "bender" crystal units in the arrangement of Figure 26;

Figure 30 is a diagrammatic representation of the principle of operation of the double-bender type of system of Figures 26—29, showing how the crystal elements tend to shorten and lengthen and thereby to bend under an applied voltage;

Figure 31 is an exploded view of a two-crystal element with intermediate as well as external electrodes, of either "bender" or "twister" type;

Figure 32 shows diagrammatically the light ray paths of a crystal and optical system including diaphragms, applicable to the systems of either Figure 1 or Figure 33;

Figure 33 shows for a modified form of my invention the arrangement of the crystal and optical elements with a semi-lunar diaphragm in the beam incident on the crystal mirror, and a slit diaphragm in the path of the reflected ray, to produce a triangular beam;

Figure 34 shows in detail a slit diaphragm with the apex of the projected triangular light beam in zero position in register with the slit;

Figure 35 shows the slit diaphragm of Figure 34 with the projected triangular light beam positioned with the slit entirely transverse thereof;

Figure 36 shows the slit diaphragm with a plurality of different successive positions of the triangular light beam corresponding to different displacements of the crystal and its mirror; and

Figure 37 shows a background noise-reducing amplifier circuit for the input of the crystal unit, with an automatic crystal bias control.

As above stated, I find that a desirable form of crystal is Rochelle salt suitably cut, because of its relatively large piezoelectric effect. Other crystals known to possess piezoelectric properties may also be used. Rochelle salt is deliquescent, and should be protected from moisture by some suitable protective coating such as a suitable varnish or collodion.

The Rochelle salt crystals which I employ are of substantially uniform thickness throughout their length, and for the purposes here in view, of the order of one-sixteenth inch thick.

I provide preferably electrodes on Rochelle salt crystals which are formed of thin laminae of leaves of gold, silver, or other noble metal, to avoid corrosion, because of the sulphate ion present, and I preferably attach these electrodes to the crystals with nitrocellulose, balsam, varnish, rosin, similar gummy compound, or like substance.

The piezoelectric sound recording system which I provide is essentially a voltage operated system, and hence has minimum distortion.

Referring to the figures in detail, in Figure 1, an exciting light source is shown at 1, which is advantageously a high-frequency actinic light source excited by a voltage of frequency above 20,000 cycles. The beam of light from source 1 passes through condensing lens 2 and thence to a diaphragm 3 having a pair of apertures 4 and 5 which provide two separated beams leaving diaphragm 3. 6 is a mirror element upon which the separate light beams delivered from diaphragm 3 impinge. 7 is a piezoelectric crystal element of

the "twister" type hereinabove mentioned having electrodes 8 and 9 provided with respective leads 11 and 12. The crystal element 7 is suitably mounted at its lower end, and at its free end is provided with a projecting arm 10 which carries mirror 6. Crystal element 7 may advantageously consist of two or more superposed crystal plates separated by intermediate electrodes, as shown for instance in Figure 3 and in more detail in Figure 31, and an additional lead may be connected to the intermediate electrode. The light beams reflected from mirror 6, as shown at 39^a and 39^b, pass through condensing lens 13 and slit diaphragm 14 having slit 15, cylindrical lens 16, condensing lens 17, and are jointly focussed by focussing lens 18 on the sound track 24 of film 19. The film 19 is carried around a film drum 20 past feed rollers 21 and 22. Film 19 has picture frames 23 as well as sound track 24.

The piezoelectric crystal element 7 is shown in Figure 1 as being of trapezoidal shape, which as has been stated has particular advantages, especially providing a wide frequency response. When voltage is applied to electrodes 8 and 9, the crystal 7 twists about its longitudinal axis and rotates mirror 6 through a relatively small angle and thereby applies to light beams 39^a and 39^b as reflected, the voice modulation carried by the voltage applied to electrodes 8 and 9. The reflected beams after passing through the optical system and being focussed on the sound track, produce on the sound track a photographic record of the applied sound modulation, modulated on both sides. A trapezoid about 1 1/4 inches long and 3/8 inch wide at the base is suitable.

Such use of two separate modulated light beams and modulation on both sides of the photographically recorded wave, has the advantage that there is produced twice as much sound volume, and if a film being reproduced has a scratch on one side of the wave as recorded on the sound track which would mutilate the reproduced sound if the modulation were carried only on one side of the wave, a perfectly reproduced sound can still be obtained by the modulation carried on the other side of the wave.

The showing of Figure 1 is schematic. In practice, the crystal element 7 with its electrodes, and the mirror element 6, is mounted in a suitable casing, as shown in Figures 2-7. The casing is shown at 25, and has a bottom portion 26 and a top portion 27 joined by a collar 28. The crystal element 33 is suitably mounted in an insulating plug member which closes the bottom end of casing 25, and crystal element 33 may as stated consist of two or more superposed crystal plates separated by intermediate electrodes. The external electrodes of crystal element 33 are shown at 34 and 35. The free end of crystal element 33 may carry a terminal cap 36 which may be of Bakelite or other suitable insulating material. Mirror element 31 is carried on a projecting arm 32 attached to cap 36. It is also possible to attach arm 32 to crystal 33 by cementing or other suitable manner.

Casing 25 is provided in its upper portion 27 with a recess 30 inwardly sloped to carry a window element 29 in register with mirror element 31. As shown particularly in Figure 6, window element 29 has one of its faces inclined, forming a substantially wedge shape, avoiding undesired reflections. The incident beam from a diaphragm 3 in Figure 1 is reflected from mirror element 31 after passing through window 29, and after reflection again passes through window 29

in the opposite direction. The electrodes 34 and 35 are provided with leads as 37, and if an intermediate electrode is used with a multi-layer crystal element, an additional lead may be provided connected to the intermediate electrode.

In order to provide means for avoiding undesirably great sensitivity of the mirror element and its actuating means, I preferably provide damping liquid means as shown at 38 within casing 25, which may desirably be a suitable mineral oil.

Figures 8-17 show a double "bender" type of crystal element arrangement, wherein two "benders" actuate a single mirror element. In Figure 8, the top plan view shows the top of the casing of the crystal elements and mirror, including the top 40 of the casing, the window 41 in register with the mirror element, the end portions 43 and 44 of the casing connected by the neck part 42 of the casing. Within the outer casing 40, the crystal units 45 and 46 are suitably mounted. These crystal units have a suitable protecting structure which encloses the crystal elements proper shown at 57 and 64. The crystal unit 45 is carried on casing 40 by a suitable supporting means or lug shown at 47. A liquid damping medium such as mineral oil extends throughout the casing in contact with the crystal element and mirror and is shown at 48. The structure of the crystal unit surrounding the crystal proper may have top and bottom metal plates 59 and 58, and insulating pieces shown at 61 which engage and support the crystal element proper.

The assembly of the crystal element is shown at 54, and has a terminal cap member 55 which is displaced when the crystal is actuated. A ribbon element or other similar element 49 is connected to the cap members 55 of the two crystal units 45 and 46, and passes through a chamber in the intermediate neck portion 42 of outer casing 40. Mirror element 50 is centrally carried on ribbon 49 within this central chamber. Insulating collars as of Bakelite are shown at 52 at the ends of intermediate neck portion 42, and are provided with apertures 53 through which ribbon 49 passes.

The bender type of crystal element 57 may as shown be advantageously substantially square but may also have other quadrilateral shape or other shape. For the square form, the crystal may be fixedly supported at three of its corners by suitable engaging caps, and at its free corner provided with the terminal cap 55. Crystal 57 has electrodes 62 and 63 which are provided with leads 51. Crystal element 57 may consist of two or more crystal plates with intermediate electrode, as heretofore described. Terminal cap member 55 may be of Bakelite or other suitable material. As has been explained, when voltage is applied to electrodes 62 and 63, the crystal plates constituting crystal member 57, supported and restrained in the manner described, tend to fold over or bend about an axis and to displace the free corner of the crystal element up and down from the plane of the paper in Figure 11. This bending movement of the crystal and its free corner carrying cap 55, will displace the ribbon 49 attached to the cap. The simultaneous bending action of the two crystal elements 57 and 64 at successive moments tilts ribbon element 49 and therewith mirror 50 in the manner shown in Figures 18 and 19, so that the reflected beam from a stationary light source is displaced as shown by arrow 65 in Figure 18.

The central portion 42 of casing 40 is provided

with sloped recess 56 carrying window 41 in register with mirror element 50. The ribbon 49 may be so-called "shim" ribbon, approximately one-sixty-fourth inch thick and one-eighth inch wide. For damping the bender type of crystal there may be used padding instead of oil. Expense is lessened by using the relatively cheap oil. For the twister arrangement, however, the amount of padding which would be necessary for damping would be relatively much more expensive, and it is not considered practical to use the padding for the twister type of crystal.

The exploded view of Figure 17 shows the relative arrangements of the crystal proper and the structural portions of the crystal unit. Figure 31 shows the detail of a crystal element composed of two superposed crystal plates 57^a and 57^b having external electrodes 62 and 63 and internal electrodes 60^a and 60^b, the latter being joined to a common lead. The multi-crystal plate structure shown in Figure 31 may be applied in both the twister and the bender type of crystal element. By attaching a separate lead to the intermediate electrodes, it is possible to apply thereto voltages which will apply phase-opposed potentials to the crystals.

Figure 20 shows a complete casing with a single crystal unit which employs only one crystal element, to actuate one mirror. The general arrangement of the elements corresponds to that of a double-crystal unit employing benders as shown in Figure 12, and the same reference characters are applied. The single crystal unit arrangement of Figure 20 will also bend the crystal element 57 and raise and lower the free end of the crystal, displacing therewith mirror element 50 in a manner to give satisfactory sound reproduction, although not giving the same volume and flexibility of control which may be obtained with the double bender crystal arrangement of Figure 12.

In Figures 21-25 there is shown a double-crystal unit arrangement in a single casing, employing two crystal elements of the twister type 71 and 72, with a single mirror element. The outer casing 66 comprises end portions 67 and 68 joined together by central portion 69. The central portion 69 is provided with a sloped recess and window as above described for the bender type of Figure 12. Cap members 73 are provided at the free ends of crystal elements 71 and 72, to which is attached the ribbon 49 carrying mirror element 50, the latter being in register with the window 70 of the casing. The twister crystal elements 71 and 72 are in general similar to the twister crystal element 33 of Figures 3 and 4, and may be likewise of trapezoidal shape. These crystal elements when actuated will twist the free end and thereby twist ribbon 49 and mirror 50 to produce a displacement of the reflected beam. Besides other advantages, this provision of a pair of independent crystal units means that if there is failure of one of the electrical input circuits of a crystal unit, there still will be an active crystal unit.

Figures 26-30 show an arrangement of a pair of crystal elements of the bender type for independently modulating two separate light beams, and employs two displaceable mirror elements; one for each beam. The source of exciting light 79 produces direct beam 83 and also reflected beam 82 reflected from mirror 80, which pass through condensing lens 81 and slit 84 to impinge on displaceable mirror elements 86 and 88. These mirror elements are respectively displace-

able by crystal elements 85 and 87 of the bender type, shown as substantially square and fixedly mounted at three corners, the mirror element being attached to the free corner. The reflected beams 89 and 90 respectively reflected from mirror elements 88 and 86, pass through condenser lenses 91 and slit lens unit 92 by which they are converged and focussed on sound track 97 of film 93. Film 93 is carried over drum 94 past feed rollers 95 and 96. The arrangement with two separately excited crystal elements makes possible duplicate units throughout, so that if there is any failure of a crystal unit or of a crystal input circuit, there is still a complete functioning system. The duplicate unit arrangement of Figure 26 also has the advantage of providing double the sound volume of a single unit system, and will also modulate both sides of the wave recorded on the sound track, so that if there is a scratch on one side of the recorded wave there will still be satisfactory sound reproduction from the other side of the recorded wave.

Crystal elements 85 and 87 are preferably so selected that they have substantial response to frequency ranges which are different but overlapping, the separating point being, say, 4000 cycles. There may be two separate sound tracks for the two mirrors, which may be separately reproduced by reproducing equipment particularly responsive to the different frequency ranges.

Figure 29 shows a universal mounting for crystal elements 85 and 87 each with three fixed corners, and one free corner which displaces mirror elements 86 and 88. The universal mounting comprises the erect members 76 which carry panel members 77 on which the crystal element and mirror are mounted. Figure 30 shows the displacement of bender crystal elements 85 and 87 when a voltage is applied thereto, the crystal element buckling or bending, foreshortening or lengthening and displacing the free end.

Figure 27 shows a detail of the exciter lamp 79, which may have external electrodes 98 and 99 to which is applied a high-frequency voltage from high-frequency source 75.

Figures 32-37 show a modified form of my invention wherein a triangular beam of light is projected on a slit diaphragm, the quantity of light flux passing through the slit depending on the position of the reflecting crystal mirror and hence on the sound energy applied to the crystal electrodes.

In Figure 32, 100 is a filament of an exciter lamp, here as shown as a straight-line filament. The exciter lamp is mounted in a suitable housing 101, and delivers a beam through a condensing lens indicated schematically at 102. This lens delivers a cone-shaped beam 103 which passes through another lens barrel 104. At its outlet, lens barrel 104 has a semi-lunar mask or diaphragm shown at 108 in Figure 33, which passes only a segment of the circuit conical beam incident thereupon. The barrel 104 may contain no other elements than mask or diaphragm 108. The segment of light which gets past diaphragm 108 is shown at 109, and is incident on mirror 110 carried on piezoelectric crystal element 111, which crystal is provided with suitable electrodes and input connections therefor.

Because of the semi-lunar shape of diaphragm 108 and its position in the ray path, only one part of the area of mirror 110, here shown as the lower half, is illuminated by the incident beam. If mirror 110 is substantially square and posi-

tioned with one corner up as shown, the beam 112 reflected from mirror 110 will be substantially triangular with one edge substantially horizontal, as shown. Other arrangements may be employed which will produce a reflected beam having sides intersecting at a substantial angle.

A lens barrel containing condensing lenses may be positioned at 113 in the path of the reflected beam, and on its first lens element there will be formed a triangular image of the incident beam as shown at 113 in Figure 33.

The lens barrel 113 delivers a triangular beam as shown at 114. It is often possible to entirely omit lens barrel 113.

A final lens barrel 118 has at its end on which triangular beam 114 is incident, a slit diaphragm 115 having a slit 116. The triangular image of beam 114 as formed on diaphragm 115 is shown at 117. Slit 116 is positioned preferably so as to be approximately parallel to one side of this triangle. Lens barrel 118 also contains other suitable condensing and focussing lenses, and the focussed beam 119 delivered from the final lens of barrel 118 is incident upon sound track 121 of film 120.

Preferably the straight-line filament 100 is parallel to the straight edge of diaphragm 108.

Piezoelectric crystal 111 is so adjusted mechanically and electrically that when no signal voltage is impressed on its electrodes, the apex of triangle 117 just touches slit 116 of diaphragm 115, as shown in Figure 34. This may be done, for instance, by applying a suitably adjusted direct-current biasing voltage to the crystal electrodes. An arrangement for securing an automatic bias control for this purpose is shown in Figure 37.

Figure 35 shows the relative position of the triangular image 117 of incident beam 114 with reference to the slit 116, when the reflected beam is displaced by a voltage applied to the crystal electrodes, as by a signal.

Figure 36 shows four successive positions of the triangular image on diaphragm 115 with reference to slit 116, corresponding to different values of voltage applied to the crystal electrodes. 117a is the image position corresponding to zero crystal voltage, 117b is the image position corresponding to a small crystal voltage, 117c the position corresponding to a stronger applied voltage, and 117d the position corresponding to a still stronger applied crystal voltage.

With the zero position of the crystal and its mirror properly adjusted with reference to slit 116, as the intensity of the applied signal voltage varies with the signal, the image 117 is displaced rapidly up and down over diaphragm 115 and slit 116, and different quantities of light flux are transmitted through slit 116 and are incident upon sound track 121.

In Figure 37 is shown a noise reduction amplifier circuit suitable for the crystal input, providing for automatic adjustment of the voltage biasing of the crystal to correct zero position, and providing for background noise reduction, when there is no signal.

The microphone is shown at 123, and its output is delivered to input amplifier 124. An input transformer 125 receives the output of amplifier 124, and delivers signal energy to the grid input of the push-pull amplifier comprising tubes 126 and 127. The output from the plates of this push-pull amplifier is delivered through by-pass condensers 132 and 134 and leads 133 and 135 to the electrodes of piezoelectric crystal element 136.

By connecting the crystal to the plates of

tubes 126 and 127, a high impedance is provided for the crystal circuit. While if the plates of these tubes were connected to the crystal through a transformer, the crystal circuit would have relatively low impedance.

A direct-current biasing voltage for adjusting the position of crystal element 136 corresponding to zero applied signal voltage is shown at 153. A potentiometer or voltage divider 151 is connected through switch 152 across battery 153, and the potentiometer terminals are connected through wires 149 and 150 to connecting points 147 and 148 on the leads of the crystal 136. By adjusting potentiometer 151, the biasing voltage applied to the crystal, and the position of the crystal and its mirror, can be adjusted as desired.

When there is no input signal voltage applied to the crystal, it is desirable that the position of the reflected beam be returned promptly to zero position. Figure 37 shows a way of accomplishing this. A portion of the output energy delivered from the plates of the push-pull amplifier is derived and applied to primary 129 of transformer 128 and delivered from its secondary 130 through coupling circuit 139 to the primary 138 of transformer 137 whose secondary 140 is connected to gain potentiometer 141. Amplifier tube 142 has its input connected to the gain potentiometer 141, and has its output connected to a potentiometer 143. Leads 145 and 146 are connected to potentiometer 143. A suitable rectifier 144 is connected in one of these leads, as in 146. The leads 145 and 146 are respectively connected to connecting points 147 and 148, and hence to the terminals of biasing battery potentiometer 151. The battery 153 and the rectifier 144 are so poled and connected that they oppose each other. By suitably adjusting gain potentiometer 141, and battery potentiometer 151, the circuit of Figure 37 will maintain the apex of triangle 117 just touching slit 116 with no applied signal voltage as shown in Figure 34, the full voltage of battery potentiometer 151 being applied to the crystal electrodes, but when input signal energy is received from the microphone, a portion of the energy is derived and rectified and applied to oppose the voltage from battery 153, so that the biasing voltage on crystal 136 is reduced and the crystal gives proper response to the applied signal voltage.

The arrangements which I have described possess marked advantages over those heretofore known, since there is provided a recording unit having extremely small inertia and immediately and accurately responsive to variations of impressed voltage. The double forms of crystal unit greatly diminish the possibility of complete failure of the recording system, and hence have great practical importance in recording historically important events, or events which can be repeated only at great expense. The metallic reflection from the mirror element makes possible the use of my invention to provide a polarized light beam as for television.

In operation, the output voltage, amplified if necessary, of the microphone or other sound source, is applied to the leads of the electrodes of the crystal elements. The exciter light, preferably with high-frequency excitation, delivers beams incident upon the mirror elements, which after reflection from the mirror elements and through the optical system, impinge upon the sound track of the film, which is moved over a recording drum in the manner usual in the art. An extremely accurate sound record dependable

in every respect, is produced by my arrangements, and extremely satisfactory results have been obtained in practice. My system has important desirable operating characteristics not possessed by types of similar devices heretofore known in the art, and very sharp and accurately delineated sound records may be obtained by my arrangement.

The high-frequency actinic exciter light source, high in ultraviolet radiation, avoids glare that would smudge peaks.

From the foregoing description of the construction of my improved recording system, the operation thereof and the method of applying the same to use will be readily understood. It will be seen that I have provided a simple, inexpensive and efficient means for carrying out the objects of the invention and while I have particularly described the elements best adapted to perform the functions set forth, it is obvious that various changes in form, proportion and in the minor details of construction may be resorted to, without departing from the spirit or sacrificing any of the principles of the invention.

Having thus described the invention, what is claimed is:

1. In a system for recording sound on film, a source of light, a piezoelectric crystal element, electrodes for said crystal element, a mirror element carried by said crystal element in spaced relation thereto, said crystal element being adapted to rotatably displace said mirror element under the application of electrical voltage to said electrodes, optical means interposed between said light source and said mirror element for delivering two substantially parallel beams of light incident on said mirror element, a light-sensitive film having a sound track, optical means for delivering on to said sound track said beams reflected from said mirror element, and a source of electrical energy of sound frequency connected to said electrodes.

2. In a system for recording sound on film, a source of light, a pair of spaced piezoelectric crystal elements mounted approximately coplanarly, electrodes for said crystal elements, a mirror element, supporting means carried by each of said crystal elements and extending substantially coplanar therewith and carrying said mirror element, said crystal elements being adapted to rotatably displace said supporting means and said mirror element therewith substantially about an axis in the plane of said crystal elements under the application of electrical voltage to said electrodes, a light-sensitive film having a sound track and positioned so that light from said source incident on said mirror element is reflected on said sound track, and a source of electrical energy of sound frequency connected to said electrodes.

3. In a system for recording sound on film, a source of light, a piezoelectric crystal element of substantially quadrilateral shape, means for fixedly supporting said crystal element at all corners thereof except one, electrodes for said crystal element, said crystal element being adapted under the application of voltage to said electrodes to flex about a transverse axis of said crystal element and to laterally displace the free corner thereof, a mirror element carried by said crystal element on said free corner thereof in spaced relation thereto, a light-sensitive film having a sound track and positioned so that light from said source incident on said mirror element is reflected on said sound track, and a source of

electrical energy of sound frequency connected to said electrodes.

4. In a system for recording sound on film, a source of light, a pair of spaced piezoelectric crystal elements mounted substantially coplanarly, electrodes for said crystal elements, said crystal elements being adapted under the application of electrical voltage to said electrodes to flex about respective transverse axes of said crystal elements and respectively bend two of their opposite portions closer together, said crystal elements being so mounted and arranged that they displace in opposite directions under a given applied voltage, a mirror element, supporting means carrying said mirror element and carried by said crystal elements in spaced and substantially coplanar relation thereto and respectively on said bendably displaceable portions thereof, a light-sensitive film having a sound track and positioned so that light from said source incident on said mirror element is reflected on said sound track, and a source of electrical energy of sound frequency connected to said electrodes.

5. In a system for recording sound on film, a source of light, a pair of spaced piezoelectric crystal elements, electrodes for said crystal elements, said crystal elements being adapted under the application of electrical voltage to said electrodes to flex about respective transverse axes of said crystal elements and respectively bend two of their opposite portions closer together, a pair of mirror elements carried respectively on said crystal elements in spaced relation thereto and respectively on said bendably displaceable portions thereof, a light-sensitive film having a sound track, optical means connected between said light source and said mirror elements for delivering two substantially parallel beams of light incident upon said mirror elements, optical means interposed between said mirror elements and said film for delivering on to the sound track on said film the beams of light from said source respectively reflected from said mirror elements, and a source of electrical energy of sound frequency connected to said electrodes.

6. In a system for recording sound on film, a source of light, a piezoelectric crystal element, electrodes for said crystal element, a mirror element carried by said crystal element in spaced relation thereto, said crystal element being adapted to rotatably displace said mirror element under the application of electrical voltage to said electrodes, a light-sensitive film having a sound track and positioned so that light from said source incident on said mirror element is reflected on said sound track, a source of electrical energy of sound frequency connected to said electrodes, and a casing surrounding and supporting said crystal element and said mirror element, said casing being filled with a liquid damping medium wherein said crystal element moves and being provided with a window in register with said mirror element.

7. In a system for recording sound on film, a source of light, a piezoelectric crystal element, electrodes for said crystal element, a mirror element carried by said crystal element in spaced relation thereto, said crystal element being adapted to rotatably displace said mirror element under the application of electrical voltage to said electrodes, a light-sensitive film having a sound track and positioned so that light from said source incident on said mirror element is reflected on said sound track, a source of electrical energy of sound frequency connected to

said electrodes, a casing surrounding and supporting said crystal element and said mirror element and being provided with a window element in register with said mirror element, said window element having its exterior face inclined at an angle to the plane of said mirror element.

8. In a system for recording sound on film, a source of light, a piezoelectric crystal element, electrodes for said crystal element, a mirror element carried by said crystal element in spaced relation thereto, said crystal element being adapted to displace said mirror element under the application of electrical voltage to said electrodes, a straight-edge diaphragm positioned with its straight edge in the path of the beam of light from said source incident on said mirror element, said mirror element being so shaped and positioned with reference to said source and said straight-edge diaphragm that the area of said mirror element illuminated by the diaphragmed beam incident thereon reflects from said mirror element a beam of substantially triangular shape, a light-sensitive film having a sound track and positioned so that the beam of light reflected from said mirror element is incident on said sound track, a diaphragm having a linear slit positioned in the path of said triangular reflected beam of light incident on said sound track with its slit substantially parallel to a side of the triangle of said beam, and a source of electrical energy of sound frequency connected to said electrodes, whereby a light flux of varying area is transmitted through said slit as the voltage applied to said electrodes varies.

9. In a system for recording sound on film, a source of light, a piezoelectric crystal element, electrodes for said crystal element, a mirror element carried by said crystal element in spaced relation thereto, said crystal element being adapted to displace said mirror element under the application of electrical voltage to said electrodes, a straight-edge diaphragm positioned with its straight edge in the path of the beam of light from said source incident on said mirror element, said mirror element being so shaped and positioned with reference to said source and said straight edge diaphragm that the area of said mirror element illuminated by the diaphragmed beam incident thereon reflects from said mirror element a beam of substantially triangular shape, a light-sensitive film having a sound track and positioned so that the beam of light reflected from said mirror element is incident on said sound track, a diaphragm having a linear slit positioned in the path of said triangular reflected beam of light incident on said sound track with its slit substantially parallel to a side of the triangle of said beam, a source of electrical voltage of sound frequency connected to said electrodes, an adjustable source of direct-current biasing potential connected to said electrodes, and means for deriving and rectifying a portion of said sound-frequency voltage and applying the recti-

fied voltage to said electrodes in opposition to said biasing potential, whereby the position of said mirror element varies with the voltage of said sound-frequency source.

10. In a system for recording sound on film, a source of light, a piezoelectric crystal element, electrodes for said crystal element, a mirror element carried by said crystal element in spaced relation thereto, said crystal element being adapted to displace said mirror element under the application of electrical voltage to said electrodes, a straight-edge diaphragm positioned with its straight edge in the path of the beam of light from said source incident on said mirror element, said mirror element being so shaped and positioned with reference to said source and said straight-edge diaphragm that the area of said mirror element illuminated by the diaphragmed beam incident thereon reflects from said mirror element a beam of substantially triangular shape, a light-sensitive film having a sound track and positioned so that the beam of light reflected from said mirror element is incident on said sound track, a diaphragm having a linear slit positioned in the path of said triangular reflected beam of light incident on said sound track with its slit substantially parallel to a side of the triangle of said beam, a source of electrical voltage of sound frequency, an electron tube amplifier having its input connected to said sound-frequency voltage source and having an output space-current path connected to said electrodes, an adjustable source of direct-current biasing potential connected to said electrodes, and means for deriving and rectifying a portion of said sound-frequency voltage and applying the rectified voltage to said electrodes in opposition to said biasing potential, whereby the position of said mirror element varies with the voltage of said sound-frequency source.

11. In a system for recording sound on film, a source of light, a pair of spaced piezoelectric crystal elements, electrodes for said crystal elements, a mirror element, supporting means carrying said mirror element and carried by said crystal elements in spaced relation thereto, said crystal elements being adapted to flex torsionally and to displace said mirror element rotatably substantially about an axis in the plane of said crystal elements under the application of electrical voltage to said electrodes, a light-sensitive film having a sound track and positioned so that light from said source incident on said mirror element is reflected on said sound track, and a source of electrical energy of sound frequency connected to said electrodes.

12. The subject matter of claim 11, said crystal elements being of substantially trapezoidal shape, and said supporting means being carried by the minor bases of said trapezoidal crystal elements respectively.

STEWART C. WHITMAN.