

1

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DISPLAY DEVICE

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This invention relates to display devices.

In my copending patent application Serial Number 36,665, filed June 16, 1960, there is disclosed an electroluminescent device for visually displaying applied input signals as discrete points on an electroluminescent panel. In one embodiment, this device comprises a rectangular electroluminescent phosphor layer affixed to one surface of a rectangular sheet of piezoelectric material. The piezoelectric sheet is provided with first and third parallel edges and second and fourth parallel edges, the second and fourth parallel edges being located between and perpendicular to the first and third edges. The surface area of the electroluminescent layer is less than that of the piezoelectric sheet and its sides are parallel to the edges of the sheet. A transparent conductive layer is placed over the electroluminescent layer while a common grounded conductive layer is secured to the other side of the piezoelectric sheet.

First, second, and third electrodes are secured to the piezoelectric sheet between its first, second, and third edges respectively and the electroluminescent layer. Thus, the first and third electrodes are parallel to each other and adjacent to opposite sides of the electroluminescent layer while the second electrode is perpendicular to the first and third electrodes. All four edges of the sheet are provided with terminations which absorb, substantially without reflection, any incident elastic waves.

A first voltage pulse applied between the first electrode and the grounded layer produces a mechanical strain in the piezoelectric sheet proportional to the amplitude of the first pulse. As the strain changes, a disturbance in the form of a first plane elastic wave accompanied by a first electric field, is propagated from the first electrode toward the opposite edge of the sheet where it is absorbed by the termination. The intensity of the electric field is proportional to the time rate of change of the strain that produced it; i.e. the intensity of the first electric field is proportional to the first time derivative of the first pulse.

Similarly, second and third voltage pulses applied between the second and third electrodes respectively and the grounded layer produce second and third plane elastic waves. Each of these waves is accompanied by an electric field which is propagated from the corresponding electrode toward the opposite edge of the sheet where it is absorbed. The intensity of the second electric field is proportional to the first time derivative of the second voltage pulse, while the intensity of the third electric field is proportional to the first time derivative of the third voltage pulse.

By applying voltage pulses to all three electrodes simultaneously, three elastic waves are generated which intersect in a small region near the center of the square electroluminescent layer. The intensities of the three electric fields produced by the three waves are additive, resulting in a bright spot of light at the center of the layer. By adjusting the relative timing of the voltage pulses applied to each of the three electrodes, any selected area of the electroluminescent layer may be caused to glow. Further by continuously varying the relative timing of the three pulses, the spot of light can be caused to "scan" the panel at a velocity determined by the timing of the applied pulses.

In another form of the display device, a fourth elec-

2

trode is secured to the piezoelectric sheet between the fourth edge of the sheet and the electroluminescent layer. A voltage pulse applied between this electrode and ground produces a fourth elastic wave accompanied by an electric field which propagates from the fourth electrode toward the opposite edge of the sheet where it is absorbed. By applying the voltage pulse to the fourth electrode at the correct instant of time relative to the time of application of pulses to the other three electrodes, the four waves are caused to intersect upon the selected point resulting in a bright spot of light in the electroluminescent layer at this point. Since the electric fields are additive, the use of four waves instead of three results in a brighter and more intense image.

Regardless of how many electrodes are used, the brightest spot on the electroluminescent layer is always located at the point where all of the waves simultaneously intersect since it is at this point that the greatest voltage is applied across the layer. However, depending upon the magnitude of the applied voltage and the type of electroluminescent phosphor employed, secondary light outputs may also be produced in the electroluminescent layer wherever two of the waves intersect. This secondary light may create a background illumination which tends to reduce the contrast ratio. Contrast ratio may be defined as the ratio of the light emitted at a selected point on the electroluminescent layer to the light emitted by the remainder of the electroluminescent layer during the time required for an elastic wave to traverse the layer.

For example, in the display device utilizing first, second, and third electrodes wherein the first and third electrodes are parallel to each other, and the second electrode is perpendicular to the first two, the waves initiated at the three electrodes will intersect at a selected point. Assuming that each wave applies a voltage v , across the electroluminescent layer, the total voltage across the layer at the selected point is $3v$. However, in addition to the voltage $3v$ at the selected point, the waves intersect along diagonal lines as well, producing voltages equal to $2v$ along these lines. Specifically, with three electrodes, spurious faint lines of light will be emitted by the electroluminescent layer along the diagonals produced by the intersection of the first and second and second and third elastic waves. In addition, a spurious vertical line of light will appear along the intersection of the first and third elastic waves through the selected point. When four electrodes are provided, the voltage at the selected point where all four waves intersect is $4v$ but, again, spurious voltages equal to $2v$ are produced wherever two elastic waves meet.

Although the ratio of the voltages across the electroluminescent layer at the selected point to the voltage at the other intersection of the elastic waves may be only 3 to 2 or 4 to 2 , the contrast ratio is usually considerably higher. This is because the brightness of the light emitted by the electroluminescent layer is a nonlinear function of the voltage applied across it, the increase in brightness being relatively large for a given increase in voltage. Although the contrast ratio of the display devices described is quite satisfactory for many applications it has been found that, in some cases, it is desirable to increase the contrast ratio still further.

Accordingly, it is an object of this invention to provide an electroluminescent display device in which there is practically no background illumination when compared with the brightness of the image.

Another object is to provide an electroluminescent display device having a high contrast ratio.

Still another object is to provide an electro-luminescent display device in which a high contrast ratio is achieved without degradation of the image resolution.

Yet another object is to provide an electroluminescent

display device which presents a relatively low capacitance load to an applied modulation source.

A further object is to provide a new and improved electroluminescent display device characterized by the absence of spurious lines on the surface of the electroluminescent panel.

A still further object is to provide a display device which is relatively simple and inexpensive to manufacture.

In the present invention, there is provided a display device comprising a piezoelectric element, an electrically non-linear element and an electroluminescent layer electrically coupled in series between a pair of spaced conductors. The non-linear element is of the type wherein the impedance decreases as the voltage applied across the element increases. Stated another way, the current through the element varies according to the equation $I = kV^n$, where I is the current through the non-linear element, V is the voltage across it and n is a number greater than 1. Means are provided for exciting the piezoelectric element thereby generating a voltage across the non-linear element and across the electroluminescent layer. The larger the magnitude of this voltage, the lower is the resistance of the non-linear element and, therefore, the larger is the percentage of the total voltage that appears across the electroluminescent layer. Also, since the electroluminescent layer is essentially capacitive, the voltage across the layer reaches a maximum at a rate determined by the magnitude of the charging current through the non-linear element.

In one form of the invention, a rectangular sheet of piezoelectric material is provided having first and second surfaces. An electroluminescent layer is affixed to the first surface of the piezoelectric sheet while one side of a non-linear resistance layer is secured to the second surface. A transparent conductive film is placed over the electroluminescent layer and a ground conductor is secured to the other side of the non-linear layer. Pairs of electrodes are fastened to opposite surfaces of the piezoelectric sheet at locations adjacent the electroluminescent layer.

When voltages are applied between the electrode pairs attached to the piezoelectric sheet, elastic waves accompanied by electric fields are propagated at constant speed toward the opposite ends of the sheet. At the point where all of the elastic waves intersect, the non-linear resistance and electroluminescent layers are subjected to a maximum voltage. Because of the relatively high voltage at the intersection, the initial current through the non-linear layer is very much higher at this point and, therefore, the voltage across the electroluminescent layer (and consequently the brightness of the spot) reaches a high value before the waves have swept past the intersection.

At all other points where only two elastic waves intersect (or where the voltage produced by an elastic wave coincides with a voltage applied between the transparent and ground conductors) the total voltage across the non-linear resistance and electroluminescent layers is less than at the point where all of the waves converge. As a result, the initial current through the non-linear layer at these secondary locations is very much less than at the point where all of the waves intersect. Thus, the voltage across the electroluminescent layer reaches only a small percentage of the total available voltage during the time when the two waves sweep through their intersection and the light emitted by the electroluminescent layer at the secondary intersections is insignificant.

The above objects of and the brief introduction to the present invention will be more fully understood and further objects and advantages will become apparent from a study of the following description in connection with the drawings, wherein:

FIG. 1 is a cutaway perspective view of one embodiment of a display device utilizing the invention;

FIG. 2 is a cross-sectional view of the display device of FIG. 1; and

FIG. 3 is a log-log plot depicting the instantaneous current density-voltage characteristic of a typical non-linear resistance layer used in the device of FIG. 1.

Referring to FIGS. 1 and 2 there is shown a thin, square, polarized, ceramic piezoelectric sheet 10 comprising a lead titanate-lead zirconate mixture. An electroluminescent layer 11, having a square surface area smaller than that of the piezoelectric sheet 10, is placed in intimate contact with one surface of the sheet and a non-linear resistance layer 12 is affixed to the other side of the sheet. The non-linear resistance layer 12 may be of the type disclosed in my copending application Serial No. 72,789, filed November 30, 1960, which consists of an essentially non-photo-conductive cadmium sulfite powder embedded in an epoxy resin. FIG. 3 is a typical curve showing the current density in the non-linear resistance layer one microsecond after a voltage step is applied across the layer.

A first electrode 19 extending across the entire width of the electroluminescent layer 11 is secured to the piezoelectric sheet adjacent one edge of layer 11 while second, third, and fourth electrodes 20, 21 and 22 are secured to the piezoelectric sheet 10 adjacent the other edges of layer 11. While four electrodes have been illustrated, it shall be understood that the non-linear resistance layer of this invention may be used with a piezoelectric sheet having any number of electrodes attached thereto.

A grounded conductive layer 13 is attached to the bottom of non-linear resistance layer 12 while grounded electrodes 19a (not shown), 20a, 21a (not shown), and 22a are secured to the bottom of the piezoelectric sheet 10 below corresponding top electrodes 19, 20, 21, and 22.

A transparent conductive layer 14 is affixed to the top of the electroluminescent layer 11. Layer 14 may be connected directly to grounded conductive layer 13 or a source of modulating voltage 30 may be coupled across layers 14 and 13 by means of a switch 31. Satisfactory operation may also be obtained if the external connection between layer 14 and layer 13 is omitted. Each edge of the piezoelectric sheet 10 is terminated in such manner as to absorb, substantially without reflection, any incident elastic wave propagated in the sheet. This is accomplished by coating the edges and immediately adjacent portions of sheet 10 with lead to provide terminations 15, 16, 17 and 18.

The application of a voltage pulse between electrode 19 and grounded electrode 19a causes a first elastic wave to be propagated across the piezoelectric sheet 10 at constant speed toward absorbing termination 17. This wave is accompanied by an electric field having an intensity proportional to the time rate of change of the pulse applied to electrode 19. A reverse wave also emanates from electrode 19 but is absorbed by termination 15 without affecting the display. Similarly, voltage pulses applied to electrodes 20, 21 and 22 cause second, third, and fourth elastic waves, accompanied by corresponding electric fields, to be propagated at the same speed as the first wave toward terminations 18, 15, and 16 respectively.

As each of the waves emanating from adjacent perpendicular electrodes intersect, a pulse voltage having an amplitude equal to 2 v. is applied across the electroluminescent and non-linear resistance layers in series. These voltages occur along diagonal lines forming the loci of the intersections of the waves from perpendicular pairs of electrodes 19 and 20, 20 and 21, 21 and 22, and 22 and 19. In addition, voltages equal to 2 v. appear across the non-linear and electroluminescent layers along vertical and horizontal lines formed by the intersection of waves from opposite electrodes 19, 21 and 20, 22 respectively. However, due to the high resistance of the non-linear resistance layer 12 the current charging the electroluminescent layer 11 at each point of intersec-

tion is quite low and therefore the voltage appearing across layer 11 is insufficient to produce visible light.

When voltage pulses are applied to the four electrodes 19-22 simultaneously, the four elastic waves meet at the center of the electroluminescent layer 11. By applying voltage pulses to electrodes 19-22 at different instants of time, the four waves can be made to intersect at any selected point on the electroluminescent layer 11. At the point of intersection of the four waves, the voltage across the electroluminescent and non-linear layers is equal to 4 v. Almost all of this voltage is applied initially across non-linear resistance layer 12 driving its resistance down and causing a large charging current to flow into the portion of electroluminescent layer 11 at the point of intersection. The large charging current produces a rapid increase in the voltage across layer 11 and, as a result, a relatively intense spot of light is emitted by the electroluminescent layer at the intersection of the four elastic waves. The light emitted from the electroluminescent layer 11 at the point where the voltage is 2 v. is insignificant when compared to the intensity of the image at the intersection where the applied voltage equals 4 v. As shown in the log-log plot of FIG. 3, the current density in a typical non-linear resistance layer is approximately twenty five times as great one microsecond after a voltage step of 200 volts is applied to it as it is one microsecond after a step of 100 volts is applied across the layer.

When switch 30 is thrown to connect the modulation generator 31 across electrodes 13 and 14, an additional voltage is superimposed on that produced by the elastic waves traversing the piezoelectric sheet 10. As before the non-linear resistance layer serves to reduce all background light to insignificant proportions. Also, the presence of non-linear resistance layer 12 in series with electroluminescent layer 11 reduces the capacitive load presented to the modulation source thereby permitting more efficient operation.

In another form of the invention disclosed in my co-pending application Serial No. 855,419, filed November 25, 1959, only two electrodes 19 and 20 are included, electrodes 21 and 22 being omitted. In this embodiment which is suitable for producing a television type raster, the elastic waves propagated from electrodes 19 and 20 intersect along a diagonal line. In addition, a modulation voltage is applied between the conductive layers 13 and 14 in synchronism with the elastic waves. Due to the non-linearity of layer 12, its resistance is lower at the intersection of the two waves than along the lines where the modulation voltage and the electric field produced by only one wave are superimposed. Also, in those areas where only the modulation voltage is impressed, the charging current through the non-linear layer 12 is very low and therefore the voltage across the electroluminescent panel is negligible. Thus, the background illumination of the electroluminescent layer 11 is insignificant when compared with the brightness of the picture spot produced by the superposition of the two intersecting elastic waves and the modulation voltage.

As many changes could be made in the above construction and many different embodiments could be made without departing from the scope thereof, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. A display device comprising a pair of spaced conductors; a sheet of piezoelectric material; an electroluminescent layer; and a voltage responsive electrically non-linear resistance layer, said piezoelectric material, electroluminescent layer and non-linear resistance layer interposed between said pair of spaced conductors.

2. A display device comprising a pair of spaced conductors; an electroluminescent layer affixed to one of said pair of spaced conductors; a sheet of piezoelectric mate-

rial; and a voltage responsive non-linear resistance layer located adjacent said sheet of piezoelectric material, said non-linear resistance layer and said sheet of piezoelectric material being interposed between said electroluminescent layer and the other of said pair of spaced conductors.

3. A display device comprising a pair of spaced conductors; an electroluminescent layer affixed to one of said pair of spaced conductors; a sheet of piezoelectric material; a voltage responsive non-linear resistance layer located adjacent said sheet of piezoelectric material, said non-linear resistance layer and said sheet of piezoelectric material being interposed between said electroluminescent layer and the other of said pair of spaced conductors; and means for producing an electric field across said sheet of piezoelectric material.

4. A display device comprising a pair of spaced conductors; a sheet of piezoelectric material; an electroluminescent layer; and a voltage responsive non-linear resistance layer, said sheet of piezoelectric material, electroluminescent layer, and non-linear resistance layer being interposed between said pair of spaced conductors; and electrode means adapted to receive an applied voltage affixed to said piezoelectric sheet, an elastic wave accompanied by an electric field being propagated in said sheet of piezoelectric material upon excitation of said electrode means by said applied voltage.

5. A display device comprising a pair of spaced conductors; an electroluminescent layer affixed to one of said pair of spaced conductors; a sheet of piezoelectric material; a voltage responsive non-linear resistance layer located adjacent said sheet of piezoelectric material, said non-linear resistance layer and said sheet of piezoelectric material being interposed between said electroluminescent layer and the other of said pair of spaced conductors; and at least one electrode secured to said piezoelectric sheet adjacent said electroluminescent layer, an elastic wave accompanied by an electric field being propagated in said sheet of piezoelectric material when a voltage is applied across said piezoelectric sheet.

6. A display device comprising a pair of spaced conductors; an electroluminescent layer affixed to one of said pair of spaced conductors; a sheet of piezoelectric material; a voltage responsive non-linear resistance layer located adjacent said sheet of piezoelectric material, said non-linear resistance layer and said sheet of piezoelectric material being interposed between said electroluminescent layer and the other of said pair of spaced conductors; and at least one pair of electrodes secured to opposite surfaces of said piezoelectric sheet adjacent said electroluminescent layer, an elastic wave accompanied by an electric field being propagated in said sheet of piezoelectric material when a voltage is applied across said pair of electrodes.

7. A display device comprising a sheet of piezoelectric material having first and second surfaces; an electroluminescent layer having one side affixed to the first surface of said sheet; a non-linear resistance layer having one side affixed to the second surface of said sheet; means for controlling the voltage between the sides of said electroluminescent and non-linear resistance layers remote from the surfaces of said piezoelectric sheet; and a plurality of electrode pairs secured to the surfaces of said sheet, an elastic wave accompanied by an electric field being propagated in said sheet when a voltage is applied across an electrode pair.

8. A display device comprising a sheet of piezoelectric material having first and second surfaces; an electroluminescent layer having one side affixed to the first surface of said sheet; a non-linear resistance layer having one side affixed to the second surface of said sheet; the sides of said electroluminescent layer and non-linear resistance layers remote from the surfaces of said piezoelectric sheet being maintained at the same potential; and a plurality of electrode pairs secured to the surfaces of said sheet, an elastic wave accompanied by an electric

7

field being propagated in said sheet when a voltage is applied across an electrode pair.

9. A display device comprising a rectangular sheet of piezoelectric material having first and second surfaces; a rectangular electroluminescent layer affixed to the first surface of said sheet; a non-linear resistance layer affixed to the second surface of said sheet; a transparent conductive layer affixed to the side of said electroluminescent layer remote from the first surface of said sheet; a conductive layer affixed to the side of said non-linear resistance layer remote from the second surface of said sheet; and first and second pairs of electrodes secured to said sheet adjacent said electroluminescent layer, said first and second pairs of electrodes being located along perpendicular edges of said rectangular sheet, elastic waves accompanied by corresponding electric fields being propagated in said sheet when voltages are applied across said electrode pairs.

10. A display device comprising a rectangular sheet of piezoelectric material having first and second surfaces; a rectangular electroluminescent layer affixed to the first surface of said sheet; a non-linear resistance layer affixed to the second surface of said sheet; a transparent conductive layer affixed to the side of said electroluminescent layer remote from the first surface of said sheet; a conductive layer affixed to the side of said non-linear resistance layer remote from the second surface of said sheet;

8

and first, second, third and fourth pairs of electrodes secured to said sheet adjacent said electroluminescent layer, each of said pairs of electrodes being located along a corresponding edge of said rectangular piezoelectric sheet, elastic waves accompanied by corresponding electric fields being propagated in said sheet when voltages are applied across each of said electrode pairs.

11. A display device comprising a sheet of piezoelectric material having first and second surfaces; an electroluminescent layer affixed to the first surface of said sheet; a non-linear resistance layer affixed to the second surface of said sheet; means for controlling the voltage between the sides of said electroluminescent and non-linear resistance layers remote from the surfaces of said piezoelectric sheet; a plurality of electrode pairs secured to the surfaces of said sheet, an elastic wave accompanied by an electric field being propagated in said sheet when a voltage is applied across an electrode pair; and termination means affixed to the edge of said sheet, said termination means absorbing substantially without reflection any incident elastic wave supplied thereto from said sheet.

References Cited in the file of this patent

UNITED STATES PATENTS

2,816,236	Rosen	Dec. 10, 1957
2,922,923	Yando	Jan. 26, 1960