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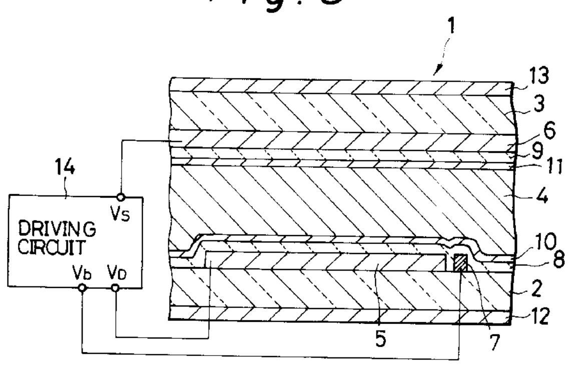
(54) **Liquid crystal display device.**

(57) A liquid crystal display device is provided to realize a tone display. The liquid crystal display is arranged to have a display panel (1) having a plurality of pixels ranged in a matrix manner. Those pixels are formed of a pair of transparent electrodes (5,6) and a liquid crystal layer (4) filled therebetween. A scan voltage (VS) is applied to one transparent electrode (5) for specifying a pixel row. A signal voltage (VD) is applied to the other transparent electrode (6) for defining luminous or non-luminous sections of each pixel. A bias electrode (7) is provided on at least one side of each pixel. Further, a bias voltage (Vb) applying unit is also provided to apply a bias voltage (Vb) for a tone display for adjusting an electric-field gradient along the pixel width onto the bias electrode (7) in synchronous with the application of the signal voltage (VD) onto the other transparent electrode.

Fig. 3



EP 0 549 337 A1

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a liquid crystal display device arranged to employ ferroelectric liquid crystal, for example.

2. Description of the Related Art

In recent days, a remark is placed on a liquid crystal display device arranged to employ ferroelectric liquid crystal. As this kind of liquid crystal, chiral smectic liquid crystal is normally considered as a representative one.

In general, the ferroelectric liquid crystal holds a spiral structure in the chiral smectic layer. In a case that the liquid crystal is injected into a thin cell, the spiral structure is loosened through the effect of the interface. As a result, two kinds of liquid crystal molecules are mingled in the liquid crystal layer, one kind of molecules, referred to as one domain, inclined by an angle of inclination $+\theta$ with respect to a normal or vertical of the smectic layer and the other kind of inclination, referred to as the other domain, inclined by an angle of inclination $-\theta$ with respect to the vertical. That is, the one domain is inclined in an opposite manner to the other domain. Then, a voltage is vertically applied to the liquid crystal keeping such a state as being directed from the back side to the front side. The vertical application of the voltage results in arranging the spontaneous polarizations into one direction, that is, obtaining the one domains keeping the uniform orientation of molecules. On the other hand, the vertical application of the opposite-polarity voltage results in obtaining the other domains keeping the opposite orientation of molecules. That is, the alternation of a polarity of a voltage to be applied to the liquid crystal causes an axis of light to change. By using this phenomenon, the liquid crystal display device may be formed if a polarizing plate is provided.

The liquid crystal display device arranged as described above enables to keep the molecular orientation before stopping the application of the voltage through the effect of the force of restricting the orientation provided on the interface. Hence, the liquid crystal display device holds a high storage capability. When the device applies to a high duty multiplex driving display, the high storage capability is very effective.

A known typical liquid crystal display device is arranged to have such a ferroelectric liquid crystal. There are provided a pair of transparent substrates opposite to each other. On the inside of one transparent substrate, one stripped transparent electrode is formed. On the inside of the other transparent substrate, the other stripped transparent electrode is formed. Both of the stripped transparent electrodes are formed to have a matrix electrode structure on the surface thereof. The one transparent electrode on the one transparent substrate and the other transparent electrode on the other transparent substrate are located so that the matrix electrodes formed thereon are crossed with each other at right angles. On the transparent electrodes, orientation films are formed through insulating films. A ferroelectric liquid crystal is filled between the transparent substrates. On the outside of the one transparent substrate, a polarizing plate is located. On the outside of the other transparent substrate, the other polarizing plate is located. The typical ferroelectric liquid crystal display device known by the inventors of the present application has been arranged as described above.

The above-mentioned known liquid crystal display device, however, provides two states of molecular orientations opposite to each other, that is, a binary display. It means that this device disadvantageously is unable to implement a tone display.

SUMMARY OF THE INVENTION

It is an object of the invention to provide a liquid crystal display device which is capable of implementing a tone display.

In carrying out the object, in a liquid crystal display device being arranged to have a plurality of pixels composed of a pair of transparent electrodes opposed to each other and a liquid crystal layer laid between the transparent electrodes and a display panel having the plurality of pixels ranged in a matrix manner, apply a scan voltage for specifying a pixel row onto one of the transparent electrodes in accordance with the row order of the ranged pixels, and apply a signal voltage for defining luminous or non-luminous sections of each of the pixels onto the other transparent electrode for driving the pixels, the liquid crystal display device is characterized by locating a bias electrode adjacent to each pixel on the side of at least one transparent electrode of the pixel and providing bias voltage applying means for applying a bias voltage for tone display for adjusting an electric-field gradient along the width of the pixel onto the bias electrode in synchronous to the application of the signal voltage onto the other transparent electrode of the pixel.

In operation, a bias voltage to be applied onto a bias electrode located adjacent to each pixel is adjusted according to the luminance to be given to the pixel. By applying such a bias voltage, an electric-field gradient takes place along the width of each pixel so that the luminance on each pixel may be varied along the width. The luminance of the pixel is adjusted according to the gradient of the luminance. It means that the tone display is allowed.

Further objects and advantages of the present invention will be apparent from the following description of the preferred embodiment of the invention as illustrated in the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Figs. 1a, 1b, 1c and 1d are views showing a principle of an operation of a ferroelectric liquid crystal;

Fig. 2 is a sectional view showing a part of a display panel included in the known ferroelectric liquid crystal display device;

Fig. 3 is an expanded sectional view showing a part of a display panel included in a liquid crystal display device according to an embodiment of the invention;

Fig. 4 is an expanded plane view showing the display panel shown in Fig. 3;

Figs. 5a, 5b and 5c are waveform diagrams showing some voltages to be applied to the display panel;

Fig. 6 is a diagram showing lines of electric force corresponding to one pixel-driven state in the display panel shown in Fig. 3;

Fig. 7 is a diagram showing lines of electric force corresponding to another pixel-driven state in the display panel shown in Fig. 3;

Fig. 8 is an expanded perspective view showing a part of the display panel included in a liquid crystal display according to another embodiment of the invention;

Fig. 9 is an expanded plane view showing the display shown in Fig. 8; and

Fig. 10 is a diagram showing lines of electric force corresponding to one pixel-driven state of the display panel shown in Fig. 8.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

At first, the known liquid crystal display device (LCD) is explained to clarify the difference between the known LCD and the LCD according to the invention.

In Figs. 1a, 1b, 1c and 1d, two kinds of liquid crystal molecules 40 are mingled in the liquid crystal layer, one kind of molecules, referred to as a domain D1, inclined by an angle of inclination +θ with respect to the vertical 41 of the smetic layer and the other kind of inclination, referred to as the other domain inclined by an angle of inclination -θ with respect to the vertical. That is, the domain D1 is inclined in an opposite manner to the domain D2. Then, a voltage is vertically applied to the liquid crystal keeping such a state as being directed from the back side to the front side as shown by a signF of Fig. 1b. The vertical application of the voltage results in arranging the spontaneous polarizations 42 into one direction, that is, obtaining the domain D1 keeping the uniform orientation of molecules. The vertical application of the opposite-polarity voltage results in obtaining the domain D2 keeping the opposite orientation of molecules as shown by a sign R of Fig. 1C.

In Fig. 2, an expanded section showing a part of a known typical liquid crystal display device arranged to have such a ferroelectric liquid crystal. As shown, there are provided a pair of transparent substrate 43 and 44 opposite to each other. On the inside of the transparent substrate 43, a stripped transparent electrode 45 is formed. On the inside of the transparent substrate 44, the other stripped transparent electrode 44 is formed. Both of the stripped transparent electrodes 44 and 45 are formed to have a matrix electrode structure on the surface thereof. The transparent electrode 45 on the transparent substrate 43 and the transparent electrode 46 on the other transparent substrate 44 are located so that the matrix electrodes formed thereon are crossed with each other at right angles. On the transparent electrode 45, an orientation film 49 is formed through an insulating film 47. On the transparent electrode 46, an orientation film 50 is formed through an insulating film 48. A numeral 51 denotes a ferroelectric liquid crystal which is filled between the transparent substrates 43 and 44. On the outside of the transparent substrate 43, a polarizing plate 52 is located. On the outside of the other transparent substrate 44, the other polarizing plate 53 is located.

Hereafter, the description will be oriented to a liquid crystal display device according to an embodiment of the invention.

Fig. 3 is a sectional view showing the liquid crystal display device. As shown, the liquid crystal display device is a ferroelectric liquid crystal display device which is arranged to locate transparent substrates 2 and 3 made of glass in opposite and fill a ferroelectric liquid crystal 4 between these substrates 2 and 3. On the inside of the transparent substrate 2, linear transparent electrodes 5 are formed in parallel. On the inside of the transparent substrate 3, linear transparent electrodes 6 are formed in parallel. Also on the inside of the transparent substrate 2, bias electrodes 7 for tone display are formed adjacent to and in parallel to the transparent electrodes 5. On the transparent electrodes 5 and the bias electrodes 7 on the transparent substrate 2, an insulating film 8 and an orientation film 10 are laminated in the describing order. On the transparent electrode 6 of the transparent substrate 3, likewise, an insulating film 9 and an orientation film 11 are laminated in the describing order.

These transparent substrates 2 and 3 are located in a manner to make both of the transparent electrodes 5 and 6 perpendicular to each other. On the outside of the transparent substrate 2, a polarizing plate 12 is provided. On the outside of the transparent substrate 3, likewise, a polarizing plate 13 is provided. A display panel 1 composed of the ferroelectric liquid crystal display device is arranged as described above. As such, the display panel 1 is arranged to provide a plurality of pixels ranged in a matrix manner. Each pixel is composed of an area of the ferroelectric liquid crystal 4 sectioned by the transparent electrodes 5 and 6 crossed with each other at right angles.

According to this embodiment of the invention, each transparent electrode 5 or 6 is formed of ITO (Indium Tin Oxide) in a manner to keep the line width 200 μ m. The bias electrode 7 is formed of molybdenum in a manner to keep a line width 20 μ m. The transparent electrode 5 keeps an interval of 5 μ m from the bias electrode 7. In this case, since the bias electrode 7 has a small area in section, it is preferable to select a metal with high electric conductivity as its material for suppressing an electric resistance.

Later, the manufacturing process of the liquid crystal display device will be described along the following steps.

At first, the transparent electrodes 5, 6 and the bias electrodes 7 are formed on the transparent substrates 2 and 3 by a known means using a photolightography and a thin film forming method such as a sputtering, a vacuum evaporating, an EB evaporating, or a CVD technique.

On the transparent electrodes 5 and the bias electrodes 7 formed on the transparent substrate 2 and the transparent electrodes 6 formed on the transparent substrate 3, SiO_2 (OCDTYPE-II manufactured by Tokyo Reactive Chemical, Ltd, for example) is spin-coated and sintered for forming the insulating films 8 and 9. On the insulating films 8 and 9, 1%-metacresol solution of nylon 6 (manufactured by Toyo Rayon, LTd.) is spin-coated and sintered for forming the orientation films 10 and 11.

On the orientation films 10 and 11 formed as described above, the rubbing processing is carried out to make the orientation films parallel or anti-parallel. Then, the resulting composition is broken into cells, each thickness of which is 1.8 μ m. The ferroelectric liquid crystal 4 is injected and sealed. The polarizing plates 12 and 13 are located on the outer surfaces of the transparent substrates 2 and 3. The resulting form corresponds to the display panel 1 shown in Fig. 3.

Fig. 4 is an expanded plane view showing a part of the display panel 1. In Fig. 4, pulse voltages VS, VD and Vb having bipolar waveforms as shown in Fig. 5 are applied to the transparent electrodes 5 and 6 and the bias electrode 7 of the display panel 1 by a driving circuit 14 shown in Fig. 3. Concretely , the scan voltage VS having a waveform shown in of Fig. 3 a is applied to the transparent electrodes 6 arranged on the display panel 1 in a matrix manner and composing pixels. The signal voltage VD having a waveform shown in Fig. 3b is applied to the other transparent electrodes 5 composing the pixels in synchronous to the transparent electrodes 6. Further, a bias voltage Vb for tone display having a waveform shown in Fig. 5c is applied into the bias electrode 7 adjacent to each pixel composed of both of the transparent electrodes 5 and 6. The scan voltage VS has the same amplitude as and is in opposite polarity to the signal voltage VD. The bias voltage Vb is variable in amplitude and in the same polarity as the scan voltage VS. The pulse width and timing are the same in the three waveforms. The amplitude of the bias voltage Vb is set to the level according to the luminance to be given on each pixel.

The application of those voltages results in causing two kinds of areas 15 and 16 to appear on one pixel as shown in Fig. 4. On the area 15, luminous and non-luminous sections are reversed and on the area 16, luminous and non-luminous sections are not reversed.

In this embodiment, each of the voltages VS, VD and Vb has a pulse width of 50 μ sec. The scan voltage VS and the signal voltage VD have the amplitude of ± 10V, respectively. The bias voltage Vb changes its amplitude from 0 to ± 30V. By changing the amplitude of the bias voltage Vb, the display reversing area 15 shown in Fig. 4 is allowed to be adjusted along the line width of the transparent electrode 5. During a blanking period when no signal is applied, the display-reversing area 15 and the display-non-reversing area 16 enable to keep the states immediately after the signals are applied.

When a voltage having the waveform shown in Figs. 5a, 5b and 5c is applied from the driving circuit 14 shown in Fig. 3 into the display panel 1, lines of electric force 17 are distributed as shown in Figs.6 and 7. The distribution shown in Fig. 6 is brought about when the scan voltage VS is at a positive polarity. The distribution shown in Fig. 7 is brought about when the scan voltage VS is at a negative polarity. In a condition that a voltage required for switching liquid crystal molecules is set by adjusting the scan voltage VS and the signal voltage VD applied to the transparent electrodes 5 and 6, it is possible to freely adjust the electric-field gradient of the transparent electrode 5 along the line width 20 (see Fig. 4) by adjusting the bias voltage Vb. As a result, as shown in Figs.6 and 7, the free adjustment is allowed to be performed about the area 18 where the molecules are switched along the line width 20 and the area 19 where the molecules are not switched. This results in making it possible to implement indefinite tone display.

Fig. 8 is a sectional view showing a liquid crystal display device according to another embodiment of the invention. The liquid crystal display device according to this embodiment is a ferroelectric liquid crystal display device which includes a display panel 21 by locating transparent substrates 2 and 3 made of glass in opposite to each other and filling the ferroelectric liquid crystal 4 between these substrates 2 and 3. The present embodiment has the same transparent electrode 6 on the side of the transparent substrate 3, insulating films 8 and 9, orientation films 10 and 11, polarizing plates 12 and 13 and driving circuit 14 as the foregoing embodiment. Hence, those components are indicated by the same numerals and are not descriptive.

According to the present embodiment, on the side of the transparent substrate 2, one bias electrode 27 for tone display is formed in parallel to the transparent electrodes 25 themselves every two transparent electrodes 25.

The transparent electrode 25 is formed of ITO so that it may keep the line width 50 μ m. The bias electrode 27 for tone display is formed of molybdenum so that it may keep the line width 6 μ m. The transparent electrode 25 keeps an interval of 2 μ m from the bias electrode 27 and the transparent electrodes ranged in parallel keep an interval of 10 μ m therebetween. The transparent electrodes 25 are ranged in a manner that one bias electrode 27 is located every two transparent electrodes 25, that is, one bias electrode 27 is located between a pair of the transparent electrodes 25 and the adjacent pair. Two transparent electrodes 25 and one bias electrode located therebetween and the transparent electrodes 6 opposite to them compose one pixel. Since the bias electrode 27 for tone display is small in section, it is preferable to select a metal with high electric conductivity for suppressing the electric resistance. As another composition, the bias electrode 27 may be a transparent electrode for preventing the possible disturbance of the display because it is located at the center of the pixel.

Like the foregoing embodiment, for forming the transparent electrodes 25 and 6 on the inside of the transparent substrates 2 and 3, respectively, it is possible to employ the known means composed of a photolithography and a thin film forming method such as a sputtering, a vacuum evaporating, an EB evaporating, or a CVD technique.

The form of the insulating films 8 and 9 and the orientation films 10 and 11, the rubbing treatment of the orientation films 10 and 11, the injection and sealing of the ferroelectric liquid crystal 4, and the disposition of the polarizing plates 12 and 13 are all implemented like the foregoing embodiment.

Fig. 9 is an expanded plane view showing a part of the display panel 21 included in the liquid crystal display device according to this embodiment. Assuming that the transparent electrode 6 of the display panel 21 is a scan side and the transparent electrode 25 is a signal side, the display panel 21 is driven in a multiplexing manner in response to a writing, an erasing or a tone bias signal like the embodiment shown in Fig. 5. By adjusting the voltage of the bias signal tuned to each signal, it is possible to control an area 28 (indicated by oblique lines) and the other area 29 for implementing indefinite tone display. The area 28 provides a display to be reversed on each pixel and the area 29 provides a display not to be reversed.

By applying a voltage having the foregoing waveform into the display panel 21, the lines of electric force 30 are distributed as shown in Fig. 10, which shows the state appearing only when the positive-polarity scan voltage VS is applied. Since the bias electrode 27 is located on the center of each pixel, the influence of a tone signal does not have any influence to only the corresponding pixel, not to the other adjacent pixels.

In the foregoing two embodiments, the bias electrodes 7 and 27 formed of a non-transparent low-resistive conductive film employs molybdenum as its material. In place, aluminum, titanium or tantalum may be used for providing the same effect. The use of a transparent electrode formed of ITO may provide the same effect if the applied voltage is enhanced.

The foregoing description about the embodiments has concerned with the ferroelectric liquid crystal display. The invention may apply to another kind of liquid crystal display for implementing the same tone display.

Many widely different embodiments of the present invention may be constructed without departing from the spirit and scope of the present invention. It should be understood that the present invention is not limited to the specific embodiments described in the specification, except as defined in the appended claims.

There are described above novel features which the skilled man will appreciate give rise to advantages. These are each independent aspects of the invention to be covered by the present application, irrespective of whether or not they are included within the scope of the following claims.

Claims

1. A liquid crystal display device arranged to have a plurality of pixels composed of a pair of transparent electrodes (5,6) opposed to each other and a liquid crystal layer (4) laid between said transparent electrodes and a display panel (1) having said plurality of pixels ranged in a matrix manner, apply a scan voltage (VS) for specifying a pixel row onto one (5) of said transparent electrodes in accordance with the row order of said ranged pixels, and apply a signal voltage (VD) for defining luminous or non-luminous sections of each of said pixels onto the other transparent electrode (6) for driving said pixels,

   said liquid crystal display device being characterized by locating a bias electrode (7) adjacent to each pixel on the side of at least one transparent electrode (5) of said pixel and providing bias voltage applying means (14) for applying a bias voltage (Vb) for tone display for adjusting an electric-field gradient along the width of said pixel onto said bias electrode (7) in synchronous to the application of said signal voltage (VD) onto the other transparent electrode (6) of said pixel.

2. A liquid crystal display device according to claim 1, wherein said bias electrode (7) is formed of molybdenum.

3. A liquid crystal display device according to claim 1, wherein the scan voltage (VS) and the signal voltage (VD) have an amplitude of ± 10v, respectively, and the bias voltage (Vb) changes an amplitude from 0 to ± 30v.

4. A liquid crystal matrix display device in which a matrix array of pixels is formed by first (5) and second (6) mutually crossing and apposed sets of transparent strip conductors, a liquid crystal layer (4) being disposed between said first and second sets of conductors, characterised in that at the positions of at least some of said pixels there is provided a bias electrode (7) alongside one of the transparent conductors (5) for controlling the pixel display tone when supplied with a tone control signal in synchronism with a display voltage applied across the liquid crystal layer of the relevent pixel, by adjusting the electric field gradient across the width of the pixel.

Fig. 1a

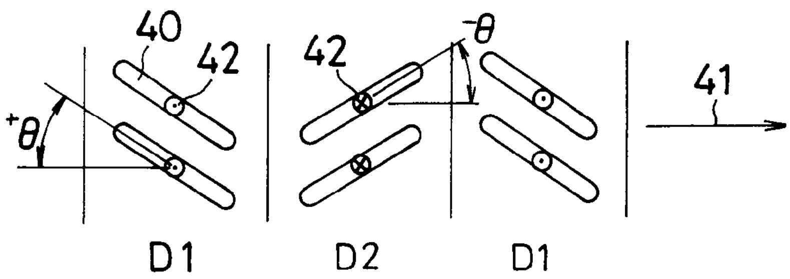


Fig. 1b

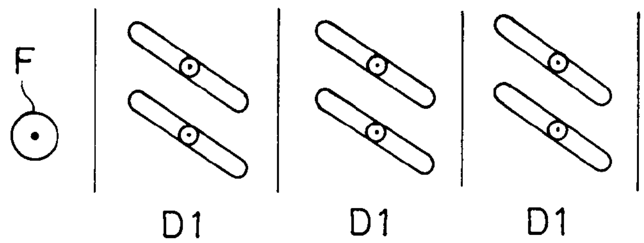


Fig. 1c

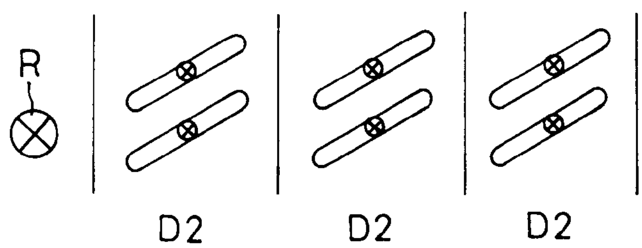


Fig. 1d

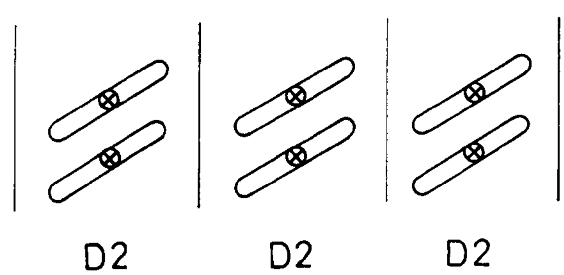


Fig. 2

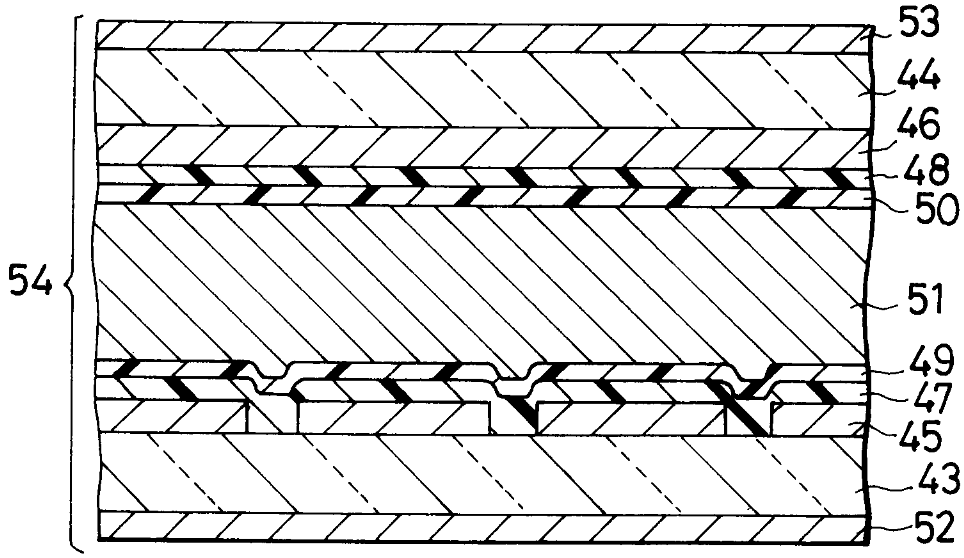


Fig. 3

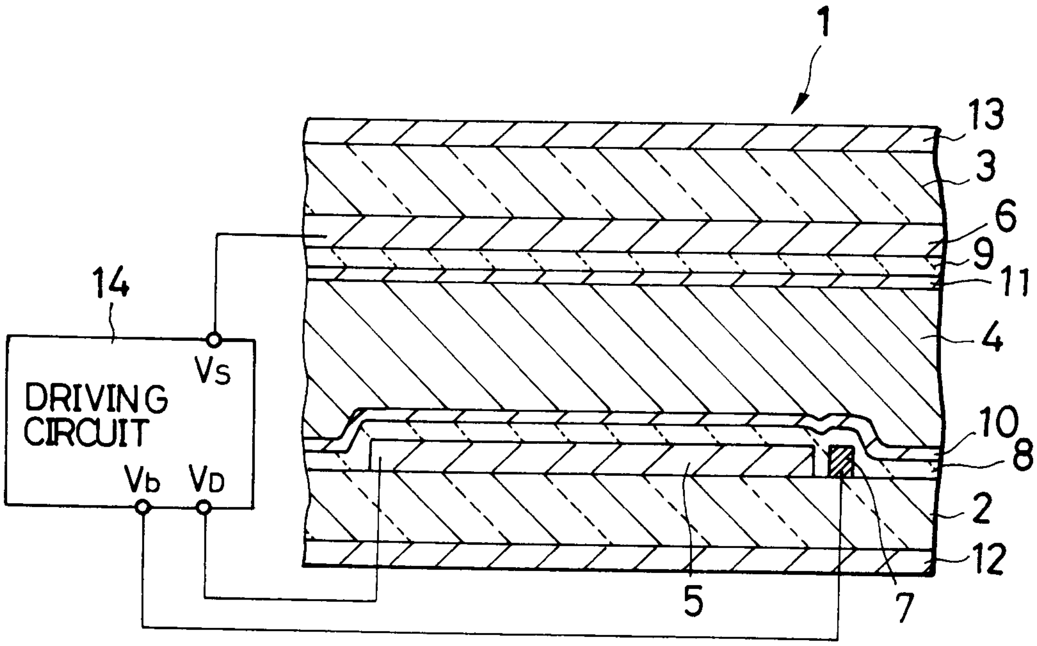


Fig. 4

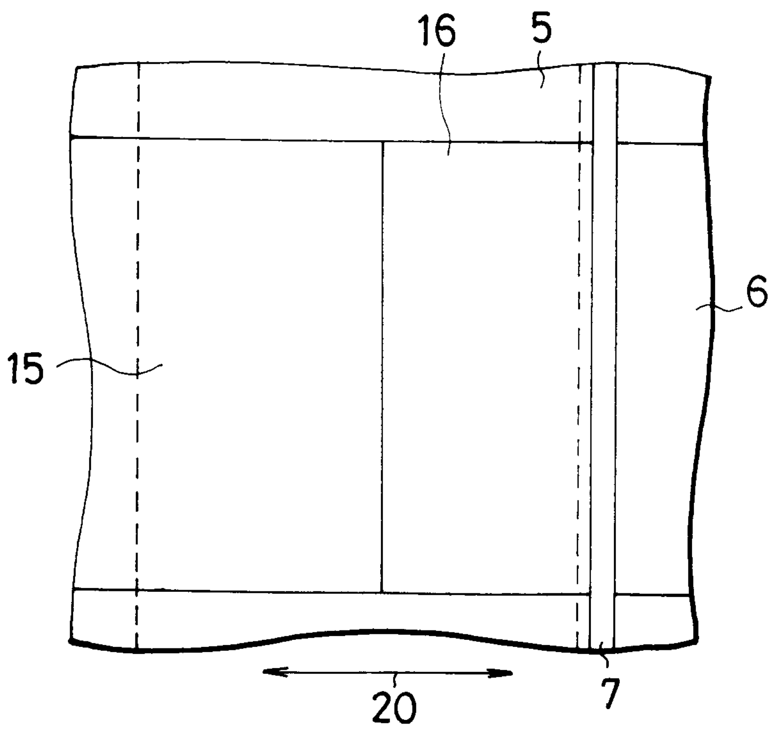


Fig. 5a

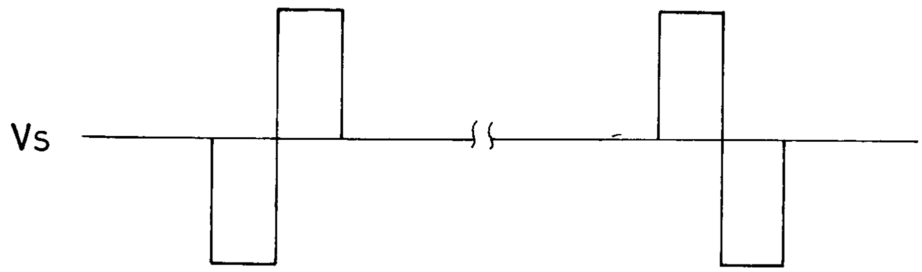


Fig. 5b

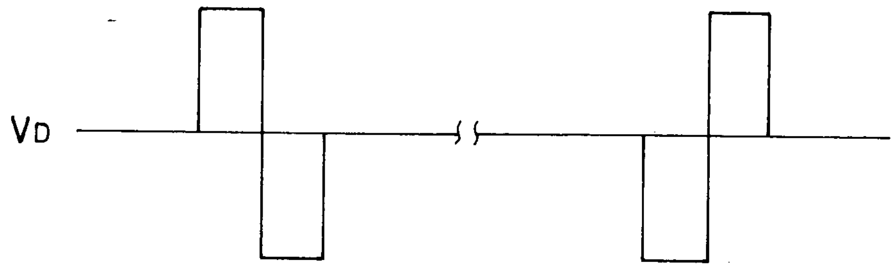


Fig. 5c

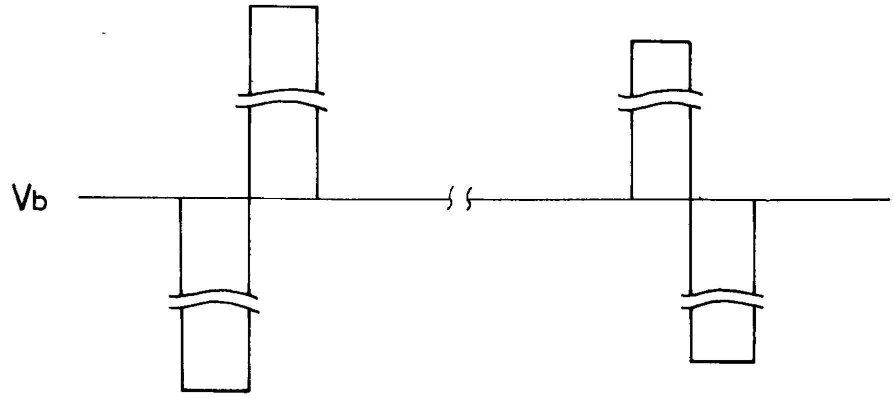


Fig. 6

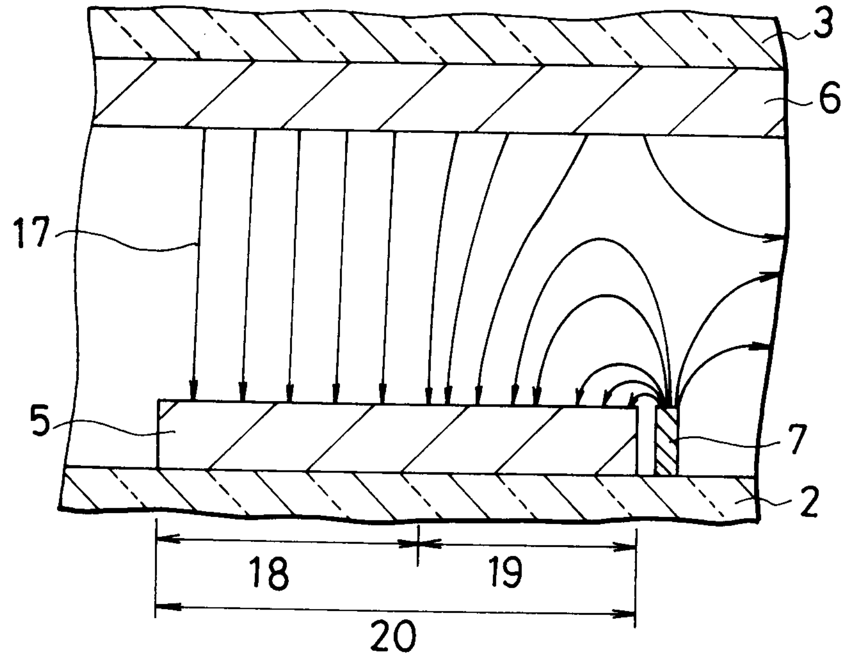


Fig. 7

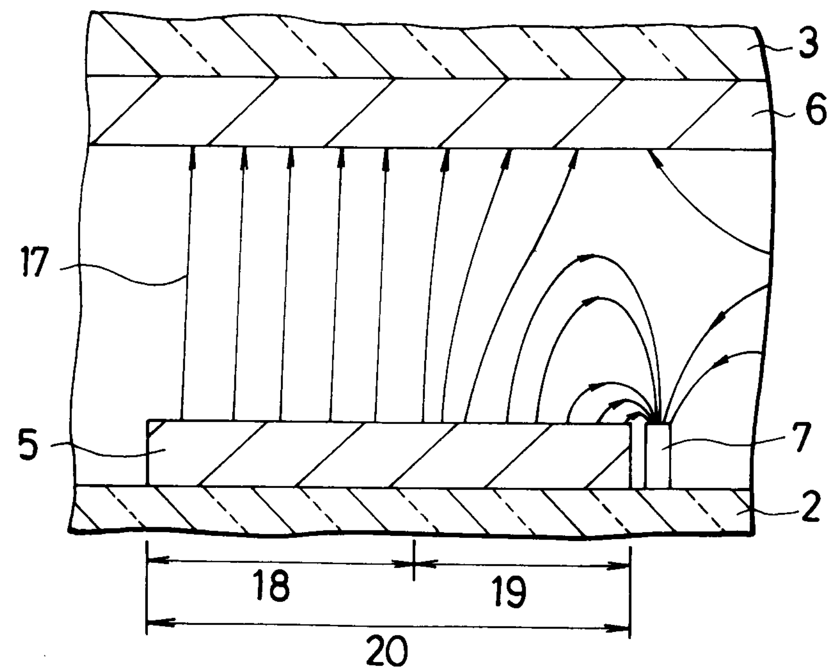


Fig. 8

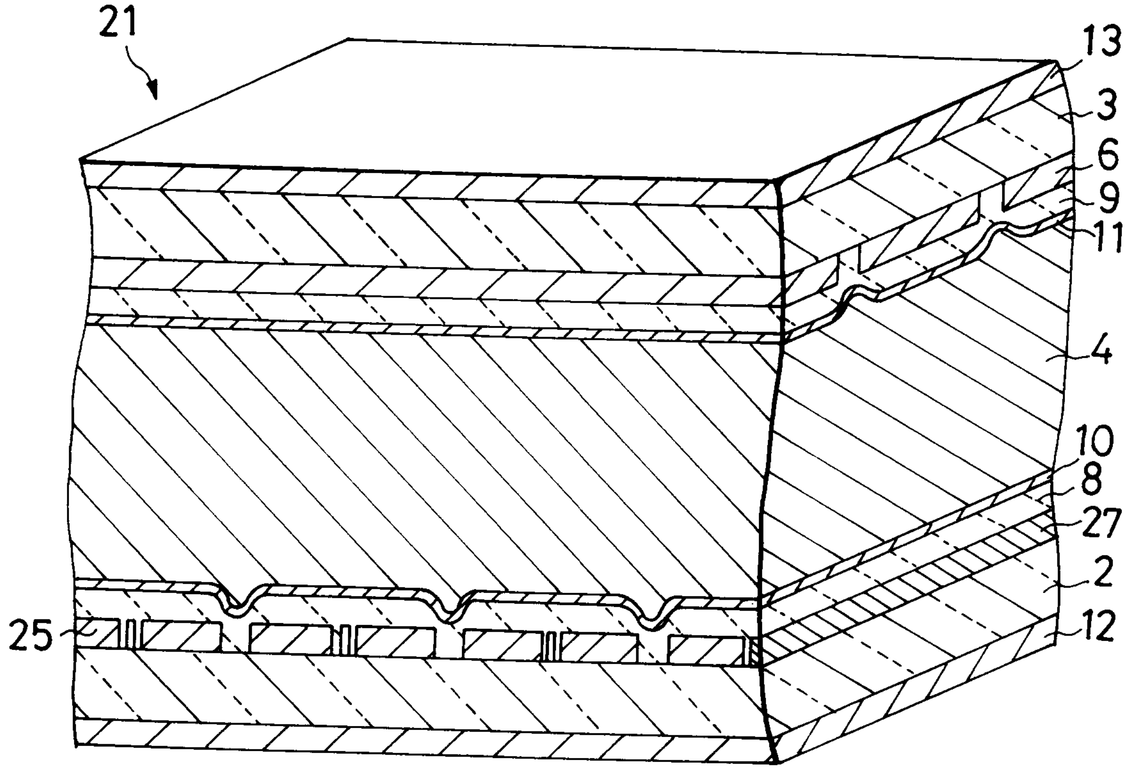


Fig. 9

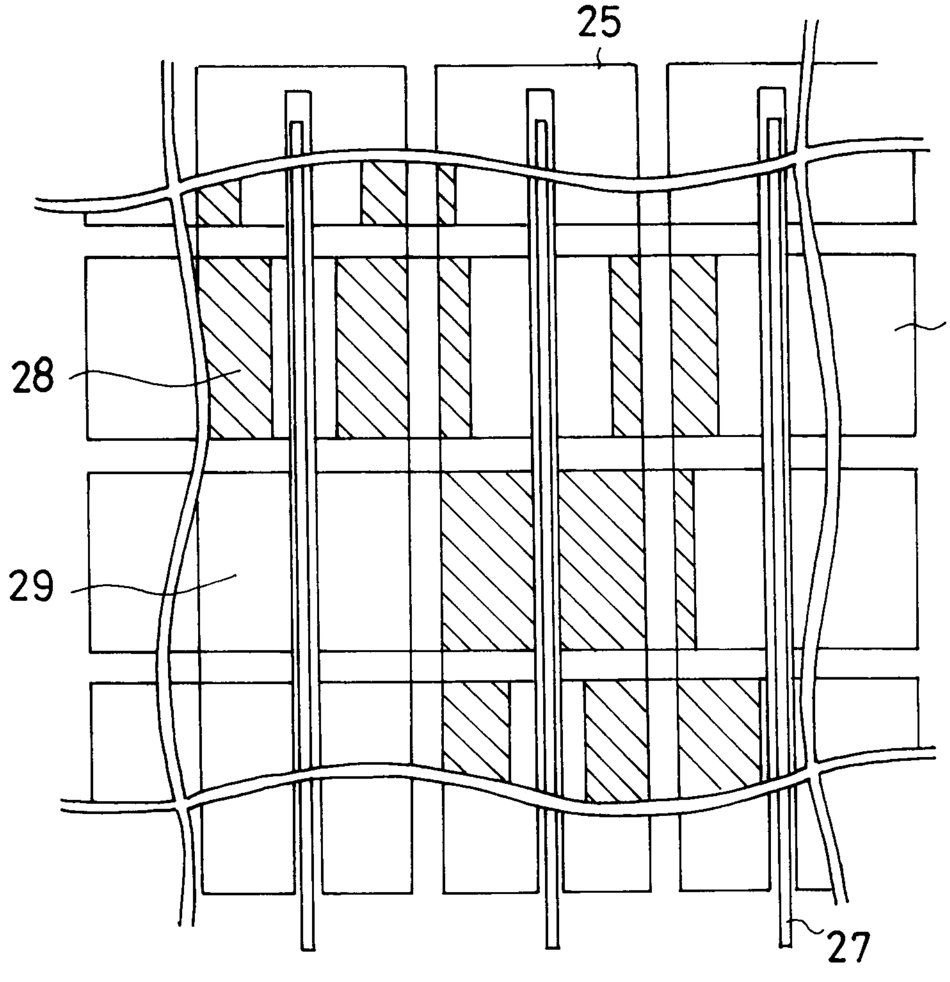
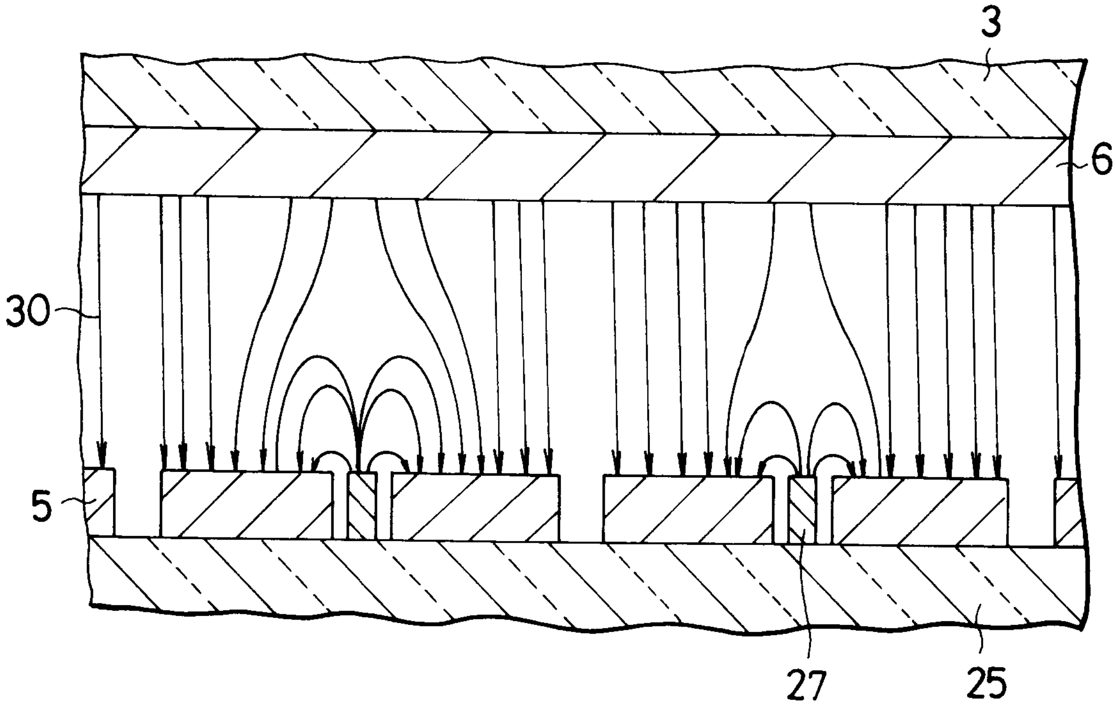


Fig. 10



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EUROPEAN SEARCH REPORT

Application Number

EP 92 31 1745

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
A	DE-A-3 711 823 (CANON K.K.) 15 October 1987 * column 17, line 11 - line 26; figures 3-8B * * column 22, line 62 - column 24, line 49; figures 16-19C * * column 36, line 53 - column 37, line 63; figures 42-44 * -----	1,4	G09G3/36
			TECHNICAL FIELDS SEARCHED (Int. Cl.5)
			G09G

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	07 APRIL 1993	CORSI F.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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P : intermediate document

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D : document cited in the application
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