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(54) Driving method for liquid crystal device

(57) A driving method for a liquid crystal device of the type comprising a pair of oppositely disposed substrates each provided with an electrode, a chiral smectic liquid crystal disposed between the substrates to form a plurality of pixels and to be placed in a monostable state under no voltage application, and a plurality of active elements each of which is provided to an associated pixel and is connected with an associated electrode so

as to effect a matrix drive of the liquid crystal device includes a step of driving the liquid crystal device so that the liquid crystal is tilted from the monostable state to provide a maximum tilt angle in actual drive smaller than a saturation tilt angle. The drive method is effective in suppressing burning or alignment state change of the chiral smectic liquid crystal, thus improving display characteristics.

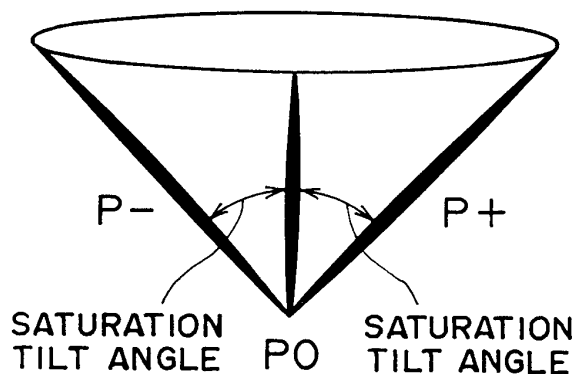


FIG. 14A

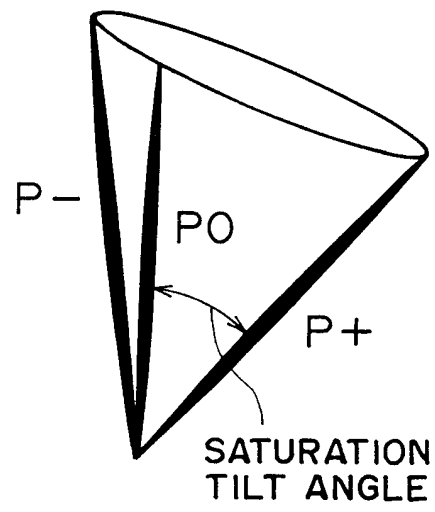


FIG. 14B

DescriptionFIELD OF THE INVENTION AND RELATED ART

[0001] The present invention relates to a driving method for liquid crystal device used as a light valve for use in a flat panel display, a projection display, a printer, etc.

[0002] As a display (apparatus) most extensively used heretofore, CRTs (cathode ray tubes) have been known and widely used as monitors for displaying motion pictures for television sets and VTRs (video tape recorders) and as monitors for personal computers. However, because of its operation principle, a CRT is accompanied with various difficulties for static picture display, such as flickering, a low picture recognizability due to scanning fringes caused by insufficient resolution, and deterioration of the fluorescent screen due to sticking or burning. Further, it has been recently found that electromagnetic wave generated from CRTs can adversely affect the human body and health of VDT operators. Moreover, a CRT necessarily requires a structure including a large volume behind the screen and is inconvenient from the viewpoints of effective utilization of data processing apparatus and space economization in offices and at home.

[0003] A liquid crystal display device is known to solve these difficulties of CRTs. For example, there has been known a type of liquid crystal device using a twisted nematic (TN)-type liquid crystal as disclosed by M. Schadt and W. Helfrich, Applied Physics Letters, Vol. 18, No. 4 (February 15, 1971), pp. 127 - 128. In recent years, a device using this type of liquid crystal and driven by TFTs (thin film transistors) as active devices or elements has been extensively developed and commercialized. This type of device (active matrix or TFT-type liquid crystal device) uses a transistor for each pixel, is free from crosstalk problem and is being produced at a fairly good productivity for display sizes of 10 - 12 inches (in diagonal) owing to rapid progress in semiconductor production technology. However, in order to reproduce motion-picture images with no problem, the TFT-type device still leaves some difficulties, such as response speed of a liquid crystal material.

[0004] On the other hand, a chiral smectic liquid crystal device of the type utilizing bistability of liquid crystal molecules has been proposed by Clark and Lagerwall (U.S. Patent No. 4,367,924; Japanese Laid-Open Patent Application (JP-A) 56-107216). In the chiral smectic liquid crystal device, the liquid crystal molecules cause switching in plane with respect to substrates, thus being expected to achieve remarkable improvement in viewing angle characteristic. The chiral smectic liquid crystal also exhibits a very quick response speed because of inversion switching thereof based on its spontaneous polarization. Further, a chiral smectic anti-ferroelectric liquid crystal device has been proposed recently by Chandani, Takezoe, et al. (Japanese Journal of Applied Physics. Vol. 27 (1988), p. L729-). In this regard, it has been quite recently discovered that a specific anti-ferroelectric liquid crystal-material provides a V (character)-shaped response characteristic (voltage-transmittance (V-T) characteristic), with little hysteresis property and advantageous to gradational display (Japanese Journal of Applied Physics, vol. 36 (1997), P.3586-).

[0005] An active matrix-type liquid crystal device using the specific anti-ferroelectric liquid crystal material for realizing high-speed display has also been proposed in JP-A 9-50049.

[0006] Further, as a ferroelectric liquid crystal (FLC) having a single stable state (monostable state), a Half V-shaped mode FLC exhibiting an asymmetric V-T characteristic depending on a polarity of an applied voltage proposed by Asao et al. (Journal of Applied Physics, vol. 38 (1999), p. 5977-) and an FLC exhibiting a V-shaped response characteristic proposed by Nito, Imanishi, et al. (Shinkaku Giho (TECHNICAL REPORT OF IEICE), EID 96 - 176, OME 96 - 94 (1997)) have been known. These FLCs are suitable for a display mode allowing a high-speed gradation control and a decreased spontaneous polarization, thus being suitable as a liquid crystal material for drive using active elements such as TFTs.

[0007] Such active matrix-type liquid crystal devices using a chiral smectic liquid crystal having (anti-)ferroelectricity has still left problems in terms of deterioration in display characteristics due to burning or sticking and/or a change in alignment state of the liquid crystal in a long term drive.

SUMMARY OF THE INVENTION

[0008] Embodiments of the present invention provide a driving method for a liquid crystal device which alleviates the above-mentioned problems.

[0009] One embodiment of the present invention provides a driving method for a chiral smectic liquid crystal device of an active matrix type which stably provides good gradational images for a long period.

[0010] According to the present invention, there is provided a driving method for a liquid crystal device of the type comprising a pair of oppositely disposed substrates each provided with an electrode, a chiral smectic liquid crystal disposed between the substrates to form a plurality of pixels, and a plurality of active elements each of which is provided to an associated pixel and is connected with an associated electrode so as to effect a matrix drive of the liquid crystal device, the liquid crystal being placed in a monostable state under no voltage application; the method comprising:

a step of driving the liquid crystal device so that the liquid crystal is tilted from the monostable state to provide a maximum tilt angle in actual drive smaller than a saturation tilt angle.

[0011] These and other objects, features and advantages of the present invention will become more apparent upon a consideration of the following description of the preferred embodiments of the present invention taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] Figure 1 is a schematic sectional view of an embodiment of the liquid crystal device of the present invention.

[0013] Figure 2 is a schematic plan view of an embodiment of an active matrix substrate of the liquid crystal device shown in Figure 1 in combination with peripheral drive circuits.

[0014] Figure 3 is a block diagram of a liquid crystal display apparatus including as a display panel the liquid crystal device according to the present invention and a graphic controller.

[0015] Figure 4 is a time chart illustrating a manner of image data communication between the liquid crystal display apparatus and the graphic controller shown in Figure 3.

[0016] Figure 5 is an equivalent circuit diagram of a liquid crystal device of an active matrix-type used in Examples.

[0017] Figure 6 is a schematic view for illustrating a deformation of layer structure in smectic phase in a chiral smectic liquid crystal device.

[0018] Figure 7 is a schematic sectional view for illustrating a surface disclination in a chiral smectic liquid crystal device.

[0019] Figures 8, 9, 10, 12 and 13 are graphs showing V-T characteristics of liquid crystal devices used in Example 1, Example 2, Comparative Example 1, Example 3 and Comparative Example 2, respectively, appearing hereinafter.

[0020] Figure 11 is a graph showing an optical response (V-T) characteristic of liquid crystal devices used in Example 3.

[0021] Figures 14A and 14B are schematic views for illustrating saturation tilt angles of liquid crystal molecules providing a V-shaped response characteristic and a Half V-shaped response characteristic, respectively.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0022] According to our study on burning or sticking phenomenon of chiral smectic liquid crystals, the burning phenomenon has been noticeably observed in such an alignment mode that liquid crystal molecules located in the vicinity of boundaries with substrates are inverted depending on ON/OFF state of a chiral smectic liquid crystal device. This inversion behavior is a switching accompanied with inversion of domain wall (domain inversion), i.e., a switching such that, when viewed from the substrate side, either one of a white (display) region or a black (display) region is broadened or narrowed while keeping a boundary (wall) therebetween. Particularly, herein, the inversion behavior refers to an inversion accompanied with a surface disclination as shown in Figure 7. Even in a monostable liquid crystal device assuming only one stable state under no voltage application, when an excessive voltage is applied to the liquid crystal device, an inversion of liquid crystal is caused to occur in a region including up to boundaries with substrates, thus leading to burning.

[0023] Figure 6 shows positions (directions) of C-directors in smectic phase of liquid crystal molecules in a chiral smectic liquid crystal device having a cell structure providing a chevron (layer) structure. At (A) is shown those under no voltage application, and at (B) is shown those under application of a high voltage. In each of (A) and (B), a left-hand view illustrates C-directors viewed from a direction perpendicular to smectic (molecular) layers (a smectic layer normal direction) and a right-hand view illustrates liquid crystal molecules viewed from a direction of smectic layers (a smectic layer direction). In Figure 6, between a pair of substrates 61a and 61b (each provided with an electrode, an alignment film, etc.), liquid crystal molecules 62 are oriented or aligned while providing C-directors 63 and directions 64 of spontaneous polarization. As shown at (A) of Figure 6, the directions 64 of spontaneous polarization at a (mid or intermediate) kink portion of the smectic layer are not perpendicular to the surfaces of the substrates 61a and 61b, thus deviating from a direction normal to the substrates. When such a liquid crystal device is supplied with a strong electric field, the spontaneous polarization directions 64 of the smectic liquid crystal molecules at the kink portion are caused to be aligned toward the electric field direction, thus being forced to exhibit a state as shown at (B) of Figure 6. The state (at (B)) is a state such that a layer inclination angle (6) at the kink portion becomes small, i.e., a deformed state of a layer structure in smectic phase. If such a deformed state is continued for a long time, the deformed layer structure remains as a structural history even when the applied electric field is removed, thus resulting in a change in electro-optical response characteristic.

[0024] This phenomenon is also similarly observed in the case of a chiral smectic liquid crystal device having a cell structure providing an oblique bookshelf (layer) structure because spontaneous polarization directions of liquid crystal molecules in a bulk state deviate from a direction perpendicular to substrates and when the device is supplied with a strong electric field, the spontaneous polarization directions are caused to be directed toward the electric field direction to place the liquid crystal molecules in a state providing a small layer inclination angle.

[0025] We have found that the above phenomenon becomes noticeable in the case of applying a high voltage to such an extent that a tilt angle (an angle formed between a molecular position (axis) under no voltage application and a molecular position (axis) under application of a voltage) at the time of actual drive of a chiral smectic liquid crystal device is below, particularly at most 95 % of, a saturation tilt angle (a maximum of a tilt angle) as specifically described hereinafter. In embodiments of the invention, by driving the chiral smectic liquid crystal device within a range such that a maximum tilt angle at the time of actual drive is below (e.g., at most 95 % of) a saturation tilt angle of a liquid crystal material used, it has become possible to prevent application of an excessive electric field for the actual drive of the liquid crystal device, thus suppressing an occurrence of burning and/or deformation of layer structure to realize stable display performances.

[0026] In a preferred embodiment, when the chiral smectic liquid crystal device is driven, e.g., actually driven by users as a display panel for a practical display apparatus, the maximum tilt angle is controlled to be smaller than, preferably at most 95 % of, more preferably at most 90 % of, further preferably at most 80 % of, the saturation tilt angle. For this purpose, a particular control means is not necessarily required. More specifically, the control of the maximum tilt angle in actual drive to be smaller than the saturation tilt angle may be effected by preliminarily setting an applied (operating) voltage to the extent that liquid crystal molecules are not tilted from their monostable position (at the time of no voltage application) to their extreme position providing the saturation tilt angle.

[0027] As described above, at the maximum tilt angle in embodiments of the invention, the chiral smectic liquid crystal device may appropriately be designed so that liquid crystal molecules do not move up to their extreme position under voltage application. In other words, the liquid crystal device does not provide the saturation tilt angle at the time of actual drive thereof.

[0028] According to the driving method of embodiments of the invention, it is possible to sufficiently ensure a luminance by increasing an apex angle of liquid crystal cone even in the case where liquid crystal molecules are completely tilted to their extreme position providing their saturation tilt angle.

[0029] Hereinbelow, the liquid crystal device driven by the driving method according to one embodiment of the invention will be specifically described with reference to Figures 1 and 2.

[0030] The liquid crystal device is a (monostabilized) chiral smectic liquid crystal device of an active matrix-type assuming a single stable state at the time of no voltage application.

[0031] Figure 1 is a schematic sectional view of an embodiment of an active matrix-type chiral smectic liquid crystal device and Figure 2 is a schematic plan view of an embodiment of an active matrix substrate in such a state that the liquid crystal device shown in Figure 1 is connected with peripheral drive circuits.

[0032] Referring to these figures, the liquid crystal device includes a pair of substrates 11 and 12, a plurality of pixel electrodes 13, a plurality of TFTs 14, an alignment control layer 15, a common electrode 16, an alignment control layer 17, a (chiral smectic) liquid crystal layer 18, a spacer 19, a sealing agent 20, scanning signal lines 23 and data signal lines 25. The liquid crystal device is connected with a scanning signal line driver 21 through the scanning signal lines 23 via scanning signal line terminals 24 and a data signal line driver 22 through the data signal lines 25 via data signal line terminals 26.

[0033] The liquid crystal device includes the pair of substrates 11 and 12 disposed opposite to each other and the liquid crystal layer 18 disposed between the substrates 11 and 12. In this embodiment, the substrate 11 is an active matrix substrate and the substrate 12 is an opposite substrate. These substrates 11 and 12 may generally be formed of a transparent material, such as glass or plastics.

[0034] The liquid crystal device in this embodiment is of a transmission-type but may be modified into a reflection-type liquid crystal device, e.g., by changing the substrate 11 to a silicon substrate etc.

[0035] On the substrate 11, the plurality of transparent pixel electrodes 13 and corresponding active devices or elements 14 (TFTs in this embodiment) connected with the pixel electrodes, respectively, are disposed in a matrix form. The active devices 14 may preferably be transistors each comprising a semiconductor of amorphous silicon, polycrystalline silicon, microcrystalline silicon or single-crystalline silicon. Each of the TFTs 14 as the active devices may ordinarily be comprised of, a gate electrode disposed on the substrate 11, a gate insulating film covering the gate electrode, a semiconductor layer formed on the gate insulating film, and a source electrode and a drain electrode formed on the semiconductor layer.

[0036] On the substrate 11, as shown in Figure 2, the scanning signal (gate) lines 23 are disposed in the row direction of the pixel electrodes 13 and the data signal (source) lines 25 are disposed in the column direction of the pixel electrodes 13. Each of the TFTs 14 is electrically connected with a corresponding scanning signal line 23 via its gate electrode and with a corresponding data signal line 25 via its source electrode, respectively. The scanning signal lines 23 are connected via their terminal portions 24 to the scanning signal line (row) driver 21. The data signal lines 25 are connected via their terminal portions 26 to the data signal line (column) driver 22. The scanning signal line driver 21 supplies gate-on signals to the scanning signal lines 23 by successively selecting the scanning signal lines 23. In synchronism with therewith, the data signal line driver 22 supplies data signals corresponding to display data to the data signal lines 25, respectively.

[0037] The scanning signal lines 23 are coated with the gate insulating film except for the terminal portions 24, and the data signal lines 25 are formed on the gate insulating film. The pixel electrodes 13 are also formed on the gate insulating film and partially connected with corresponding drain electrodes of the TFTs 14, respectively.

[0038] On the other (opposite) substrate 12, as shown in Figure 1, the common electrode 16 disposed opposite to the pixel electrode 13 (on the active matrix substrate 11) is formed. The common electrode 14 is formed of a single electrode having an area over the entire display region and supplies a referential voltage. As a result, the liquid crystal layer 18 is supplied with a voltage depending on a data signal voltage to change a resultant transmittance, thus effecting a gradational display. Further, each of the pixels may be provided with a capacitor as an auxiliary capacitance.

[0039] The pixel electrodes 13 and the common electrode 16 may generally be formed of a transparent conductive material such as ITO (indium tin oxide). In the case of preparing a reflection-type liquid crystal device, the pixel electrodes 13 may be formed of a metal exhibiting a high reflectance or may be coated with a reflection member at their upper or lower surfaces.

[0040] In a preferred embodiment, the liquid crystal device includes at least one of the alignment control layers 15 and 17. At least one of the alignment films control layers 15 and 17 may more preferably be subjected to a uniaxial aligning treatment such as rubbing.

[0041] Such a uniaxial aligning control layer may be formed in the following manner.

[0042] On the substrate, a layer (film) of an inorganic substance, such as silicon monoxide, silicon dioxide, aluminum oxide, zirconia, magnesium fluoride, cerium oxide, cerium fluoride, silicon nitride, silicon carbide or boron nitride or of an organic substance, such as polyvinyl alcohol, polyimide, polyamide-imide, polyester, polyamide, polyesterimide, polyparaxyrene, polycarbonate, polyvinylacetal, polyvinyl chloride, polystyrene, polysiloxane, cellulose resin, melamine resin, urea resin or acrylic resin is formed by solution coating, vapor deposition or sputtering, followed by surface-rubbing with a fibrous material, such as velvet, cloth or paper. It is also possible to employ oblique vapor deposition wherein an oxide (e.g., SiO) or an nitride is vapor-deposited on the substrate from an oblique direction. On the substrate, it is possible to optionally form a short-circuit prevention layer.

[0043] Particularly, in order to provide a better uniaxial aligning characteristic, it is preferred to use a rubbed polyimide film as the uniaxial aligning control layer.

[0044] The polyimide alignment control layer (film) may ordinarily be formed by applying a polyamic acid solution on the substrate, followed by curing. The polyamic acid is readily soluble in a solvent, thus being excellent in productivity. In recent years, a solvent-soluble polyimide is also commercially available, so that the resultant polyimide film may preferably be used as an alignment control layer for the liquid crystal device because of its excellent uniaxial aligning characteristic and a good productivity.

[0045] The spacer 19 is disposed between the pair of oppositely disposed substrates 11 and 12 to determine a gap between the substrates (cell gap) and may generally comprise, e.g., silica beads. The cell gap of the resultant liquid crystal device may be changed in its suitable range and/or upper limit value depending on a liquid crystal material used.

[0046] The liquid crystal layer 18 comprises a chiral smectic liquid crystal which is not particularly restricted so long as the liquid crystal assumes a monostable (single stable) state when a resultant liquid crystal device using the liquid crystal is supplied with no voltage. The chiral smectic liquid crystal may preferably comprise a ferroelectric liquid crystal or an anti-ferroelectric liquid crystal. In a preferred embodiment, the chiral smectic liquid crystal shows a saturation tilt angle of above 45 degrees in order to set a maximum tilt angle at the time of actual drive of 45 degrees, thus ensuring a maximum transmittance.

[0047] The liquid crystal device used in embodiments of the invention may preferably exhibit a V-shaped optical response (V-T (voltage-transmittance)) characteristic being symmetrical with respect to an axis (of ordinates) for representing a transmittance such that a chiral smectic liquid crystal is placed in a first alignment state providing a first transmittance under no voltage application and changed to second and third alignment states each providing a second transmittance under application of prescribed positive and negative voltages (+V₀ and -V₀), respectively, and a resultant transmittance continuously varies between the first and second transmittances depending on the applied voltage, thus providing gradational display levels. When the liquid crystal device is sandwiched between a pair of polarizers so that the first transmittance provides a darkest state and the second transmittance provides a brightest state, it becomes possible to effect a gradational display depending on the applied voltage.

[0048] Figure 14A shows a virtual cone of the chiral smectic liquid crystal for illustrating a saturation tilt angle in the case where the chiral smectic liquid crystal provides a V-shaped response characteristic.

[0049] Referring to Figure 14A, a liquid crystal molecule is located at a center position P₀ of the cone and is tilted from the position P₀ to positions P₊ and P₋ under application of positive and negative voltages, respectively. In this case, a saturation tilt angle at the time of positive-polarity voltage application and a saturation tilt angle at the time of negative-polarity voltage application are equal to each other. The saturation tilt angle is a maximum of an angle formed between the positions P₀ and P₊ (or P₋), i.e., between a monostable molecular position (under no voltage application) and an extreme molecular position (under application of a saturation voltage), and coincides with 1/2 of an apex (cone) angle of the cone of the chiral smectic liquid crystal.

[0050] The liquid crystal device used in embodiments of the invention may also preferably exhibit a Half V-shaped optical response (V-T) characteristic being asymmetrical with respect to an axis (of ordinates) for representing a transmittance such that a chiral smectic liquid crystal is placed in a first alignment state providing a first transmittance under no voltage application and changed to second and third alignment states providing mutually different transmittances under application of prescribed positive and negative voltages (+V₀ and -V₀), respectively. In this case, a maximum transmittance T₂ under application of a voltage of one polarity and a maximum transmittance T₃ under application of a voltage of the other polarity may preferably satisfy the following relationship:

$$T_2 \geq 5 \times T_3.$$

The transmittance T₃ may also preferably be substantially zero.

[0051] Figure 14B shows a virtual cone of the chiral smectic liquid crystal for illustrating a saturation tilt angle in the case where the chiral smectic liquid crystal provides a Half V-shaped response characteristic.

[0052] Referring to Figure 14B, a liquid crystal molecule is located at a position P₀ in the vicinity of one of edges of the cone and is tilted from the position P₀ to positions P₊ and P₋ under application of positive and negative voltages, respectively. In this case, a maximum of the tilt angle at the time of positive-polarity voltage application and a maximum of the tilt angle at the time of negative-polarity voltage application are different from each other. A saturation tilt angle in this case is determined as a maximum of an angle formed between the positions P₀ and P₊. Further, in Figure 14B, the liquid crystal molecule position P₀ under no voltage application is located in the vicinity of the position P₋ (i.e., on one of the edges of the cone) but may coincide with the position P₋. In this case, the liquid crystal molecule is not tilted under application of the negative-polarity voltage. The liquid crystal molecular position P₀ may also be located in the vicinity of or coincide with the position P₊.

[0053] The above-mentioned liquid crystal device used in embodiments of the invention can constitute liquid crystal apparatus having various functions. For example, a liquid crystal display apparatus 101 having a control system as illustrated by its block diagram shown in Figure 3 may be constituted by using a liquid crystal device used in one embodiment of the invention as a display panel 103.

[0054] Referring to Figure 3, the liquid crystal display apparatus 101 includes a graphic controller 102, a display panel 103, a scanning signal (gate) line drive circuit 104, a data signal line drive circuit 105, a decoder 106, a gate line signal generator 107, a shift resistor 108, a line memory 109, a data signal generator 110, a drive control circuit 111, a graphic central processing unit (GCPU) 112, a host central processing unit (host CPU) 113, and an image data storage memory (video-RAM or VRAM) 114.

[0055] Figure 4 is a time chart illustrating a manner of data communication for transferring image data including scanning line address data and certain data format as illustrated by using a communication synchronizing means based on a SYNC signal.

[0056] More specifically, image data is generated from a graphic controller 102 in an apparatus main body and is transferred to the display panel 103 by signal transfer means as illustrated in Figures 3 and 4. The graphic controller 102 includes graphic central processing unit (GCPU) 112 and image data storage memory (VRAM) 114 as core units and is in charge of control and communication of image data between a host CPU 113 therein and the liquid crystal display apparatus 101. Incidentally, a light source (backlight) may be disposed, as desired, behind the display panel 103.

[0057] In embodiments of the invention, an optical response characteristic (V-T characteristic) of the liquid crystal device may be determined in the following manner.

[0058] A liquid crystal device is sandwiched between a pair of cross-nicol polarizers so that the liquid crystal device provides a darkest state under no voltage application, i.e., a rubbing direction of the liquid crystal device is aligned substantially with one of polarizing axes of the polarizers. The liquid crystal device is subjected to measurement of a change in transmittance by using a polarizing microscope provided with a photomultiplier while applying a voltage (e.g., a triangular wave voltage of 0 - ±5 volts and 0.1 Hz), thus obtaining a V-T curve.

[0059] The saturation tilt angle referred to herein may be determined in the following manner.

[0060] A liquid crystal device is sandwiched between right angle-cross nicol polarizers and rotated horizontally relative to the polarizers under application of an AC voltage of ±15 V to ±50 V and 1 to 100 Hz (e.g., ±15 V and 100 Hz) between a pair of substrates of the device while measuring a transmittance through the device by a photomultiplier (available from Hamamatsu Photonics K.K.) to find a first extinct position (a position providing the lowest transmittance) and a second extinct position. Then, under no voltage application, the liquid crystal device was rotated while measuring a transmittance to find a third extinct position. A saturation tilt angle is determined as a larger angle selected from an angle between the first and third extinct positions and an angle between the second and third extinct positions. Further, an angle between the first and second extinct positions is measured to as an apex or cone angle.

[0061] In embodiments of the invention, a tilt angle at the time of application of a prescribed (but arbitrary) voltage may be determined in the same manner as above. Such a tilt angle is measured as an angle between the third extinct

position and the first or second extinct position depending on the applied voltage.

[0062] Hereinbelow, embodiments of the invention will be described more specifically based on Examples and Comparative Examples.

Example 1

[0063] Two liquid crystal cells a-0 and a-1 were each prepared in the following manner.

[0064] On each of two 1.3 mm-thick glass substrates, a 700 Å-thick ITO film was formed as a transparent electrode, and thereon a 600 Å-thick TaO₅ film was formed as a short-circuit prevention layer by RF sputtering.

[0065] On one of the thus-treated glass substrates, a polyimide precursor ("SE-100", mfd. by Nissan Kagaku K.K.) was applied by spin coating, followed by hot curing to form a 50 Å-thick polyimide film, which was then subjected to rubbing treatment in an ordinary manner.

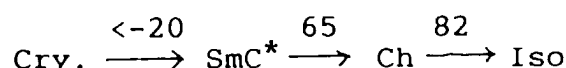
[0066] In a similar manner, a 50 Å-thick polyimide film was formed on the other substrate by using a polyimide precursor ("LQ-1802", mfd. by Hitachi Kasei Kogyo K.K.) and was similarly subjected to the ordinary rubbing treatment.

[0067] On one of the substrates, spacer beads having an average particle size of ca. 1.7 μm were dispersed and the two substrates were applied to each other so that the rubbing directions were in parallel with each other but oppositely directed (anti-parallel relationship) to form a blank cell.

[0068] Into the blank cell, a chiral smectic liquid crystal ("ZLI-4136", mfd. by E. Merck Co.) providing a saturation tilt angle of 36 degrees was injected at an isotropic liquid (phase) temperature under a reduced pressure and cooled to room temperature in ca. 1 hour.

Phase transition temperatures (°C)

[0069]



Cry: crystal phase,
SmC*: chiral smectic C phase,
Ch: cholesteric phase, and
Iso: isotropic phase

[0070] Spontaneous polarization Ps (at 20 °C): 13.8 nC/cm²

[0071] As shown above, the chiral smectic liquid crystal did not assume a smectic A phase (SmA) in the phase transition between Ch and SmC*.

[0072] The spontaneous polarization Ps was measured according to "Direct Method with Triangular Waves for Measuring Spontaneous Polarization in Ferroelectric Liquid Crystal", as described by K. Miyasato et al (Japanese J. Appl. Phys. vol. 22, No. 10, pp. L661 (1983)).

[0073] By using the thus-prepared liquid crystal cells a-0 and a-1, two active matrix-type liquid crystal devices A-0 and A-1 as shown in Figure 5 were prepared.

[0074] Referring to Figure 5, each of the liquid crystal devices A-0 and A-1 was comprised of the above-prepared liquid crystal cell (a-0 or a-1) 52 (planar area: 0.9 cm²), a single-crystalline silicon transistor 51 (ON-state resistance: 50 ohm), and a ceramic (storage) capacitor (capacitance: 2 nF). One of the liquid crystal devices was supplied with a gate (canning) signal voltage in a selection (gate-on) period of 30 μsec from a gate (scanning) signal line 23 and supplied with a prescribed data signal voltage Vop from a data signal line 25.

[0075] Specifically, the liquid crystal device A-1 was continuously supplied for 500 hours with a maximum of Vop of 4 volts providing a maximum tilt angle of 33.9 degrees, which was 94.2 % of the saturation tilt angle (36 degrees). On the other hand, the liquid crystal device A-0 was leftstanding for 500 hours under no voltage application.

[0076] Thereafter, these liquid crystal devices A-0 and A-1 were subjected to evaluation of V-T characteristic at 30 °C by using a triangular wave (0 - ±5 volts, 0.1 Hz).

[0077] V-T curves for the liquid crystal device A-1 (solid line) and the liquid crystal device A-0 (dotted line) are shown in Figure 8. In Figures 8, 9, 10, 12 and 13, a transmittance providing a brightest state in an initial stage of liquid crystal device is taken as 100 %.

[0078] As shown in Figure 8, the two V-T curves for the liquid crystal devices A-0 and A-1 were close to each other and merely provided a maximum difference in transmittance of ca. 4 %.

Example 2

[0079] Two active matrix-type liquid crystal devices A-2 (for continuous voltage application) and A-0 (for continuous no voltage application) were prepared and evaluated in the same manner as in Example 1 except that the maximum Vop value (4 volts) was changed to 3.5 volts (for the device A-2) providing a maximum tilt angle of 31.7 degrees (88.1 % of the saturation tilt angle (36 degrees)).

[0080] The results are shown in Figure 9.

[0081] The resultant V-T curves for the liquid crystal device A-2 (solid line) and the liquid crystal device A-0 (dotted line) merely provided a maximum difference in transmittance of ca. 2 %.

Comparative Example 1

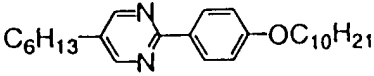
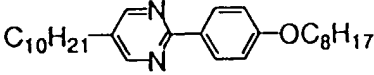
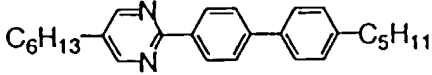
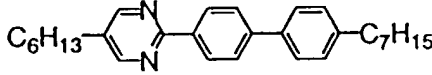
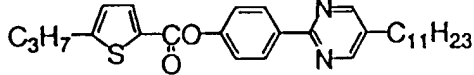
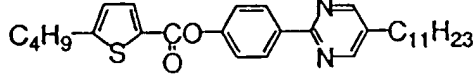
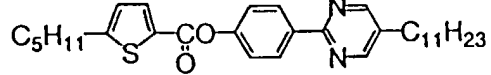
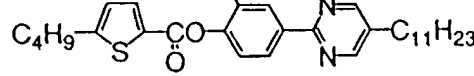
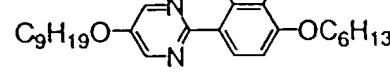
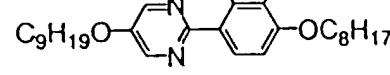
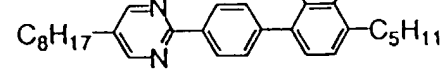
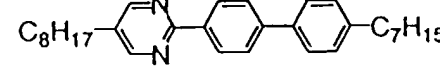
[0082] Two active matrix-type liquid crystal devices A-3 (for continuous voltage application) and A-0 (for continuous no voltage application) were prepared and evaluated in the same manner as in Example 1 except that the maximum Vop value (4 volts) was changed to 6 volts (for the device A-3) providing a maximum tilt angle of 36 degrees (100 % of the saturation tilt angle (36 degrees)).

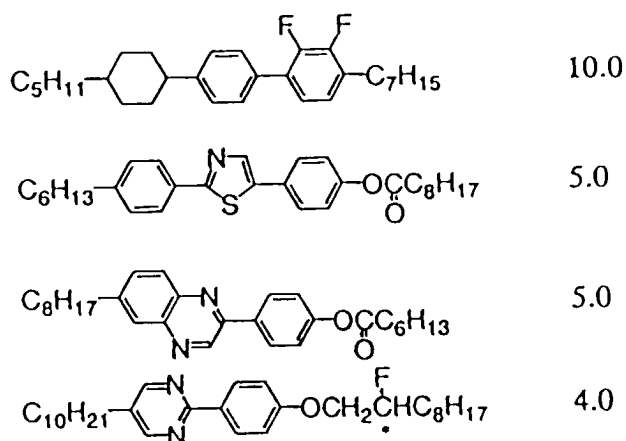
[0083] The results are shown in Figure 10.

[0084] The resultant V-T curves for the liquid crystal device A-3 (solid line) and the liquid crystal device A-0 (dotted line) provided a maximum difference in voltage for giving identical luminance (transmittance) of ca. 200 mV, which corresponded to a maximum difference in transmittance of ca. 15 %.

Example 3

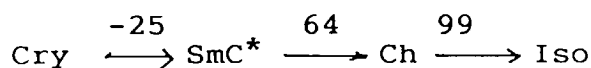
[0085] A chiral smectic liquid crystal composition LC-1 was prepared by mixing the following compounds in the indicated proportions.

	<u>Structural formula</u>	<u>wt. %</u>
5		4.0
10		4.0
15		3.5
		3.5
20		10.0
25		15.0
		10.0
30		10.0
35		3.0
		3.0
40		5.0
45		5.0



Phase transition temperature (°C)

[0086]



Ps (at 30 °C): 4.4 nC/cm²

Cone (apex) angle: 54.8 degrees

[0087] Two liquid crystal cells b-0 and b-1 were each prepared in the following manner.

[0088] On each of two 1.1 mm-thick glass substrates, a 1200 Å-thick ITO film was formed as a transparent electrode, and thereon, a polyimide precursor ("SE-7992") was applied by spin coating and pre-dried at 80 °C for 5 min., followed by hot-curing at 200 °C for 1 hour to form 500 Å-thick polyimide film.

[0089] Each of the thus-obtained polyimide film was subjected to rubbing treatment (as a uniaxial aligning treatment) with a nylon cloth under the following conditions to provide an alignment control layer.

[0090] Rubbing roller: a 10 cm-dia. roller about which a nylon cloth ("NF-77", mfd. by Teijin K.K.) was wound.

Pressing depth: 0.3 mm

Substrate feed rate: 10 cm/sec

Rotation speed: 1000 rpm

Substrate feed: 4 times

[0091] Then, on one of the substrates, spacer beads (average particle size = ca. 1.5 μm) were dispersed and the pair of substrates were applied to each other so that the rubbing directions were in parallel with each other but oppositely directed (anti-parallel relationship), thus preparing a blank cell with a uniform cell gap.

[0092] The liquid crystal composition LC-1 was injected into each of the above-prepared blank cells in its cholesteric phase state and gradually cooled to a temperature providing chiral smectic C phase to prepare liquid crystal cells b-0 and b-1.

[0093] In the above cooling step from Iso to SmC*, each of the cells was subjected to a voltage application treatment such that a DC (offset) voltage of -2 volts was applied in a temperature range of $T_c \pm 2$ °C (T_c : Ch-SmC* phase transition temperature) while cooling each device at a rate of 1 °C/min.

[0094] The thus-prepared liquid crystal cells b-0 and b-1 were evaluated in the following manner in terms of alignment state and optical response characteristics, respectively.

<Alignment state>

[0095] The alignment state of the liquid crystal composition LC-1 of each of the liquid crystal cells b-0 and b-1 was

observed through a polarizing microscope at 30 °C (room temperature).

[0096] As a result, a substantially uniform alignment state such that under no voltage application, the darkest (optical) axis was somewhat deviated from the rubbing direction and only one layer normal direction was present over the entire cell.

<Optical response to triangular wave>

[0097] Each of the liquid crystal cells b-0 and b-1 was set in a polarizing microscope equipped with a photomultiplier under cross nicol relationship so that a polarizing axis was disposed to provide the darkest state under no voltage application.

[0098] When each liquid crystal cell was supplied with a triangular wave (0 - ± 6 volts, 0.2 Hz) at 30 °C, a resultant transmittance was gradually increased with the magnitude (absolute value) of the applied voltage under application of the positive-polarity voltage. On the other hand, under application of the negative-polarity voltage, a resultant transmittance was changed with the applied voltage level but a maximum value of the transmittance was ca. 1/10 of a maximum transmittance in the case of the positive-polarity voltage application.

[0099] The result is shown in Figure 11.

[0100] Further, an average position of liquid crystal molecules in each of the liquid crystal cells b-0 and b-1 was found to be located inside one of cone edges by 3 degrees. Accordingly, each of the liquid crystal cells b-0 and b-1 provided a saturation tilt angle of 51.8 degrees (cone angle (54.8 degrees) - 3 degrees).

[0101] By using the above-prepared liquid crystal cells b-0 and b-1, two active matrix-type liquid crystal devices B-0 and B-1 as shown in Figure 5 were prepared in the same manner as in Example 1.

[0102] Referring to Figure 5, each of the liquid crystal devices B-0 and B-1 was comprised of the above-prepared liquid crystal cell (b-0 or b-1) 52 (planar area: 0.9 cm²), a single-crystalline silicon transistor 51 (ON-state resistance: 50 ohm), and a ceramic (storage) capacitor (capacitance: 2 nF). One of the liquid crystal devices was supplied with a gate (canning) signal voltage in a selection (gate-on) period of 30 μ sec from a gate (scanning) signal line 23 and supplied with a prescribed data signal voltage Vop from a data signal line 25.

[0103] Specifically, the liquid crystal device B-1 was continuously supplied for 500 hours with a maximum of Vop of 6 volts providing a maximum tilt angle of 45 degrees, which was 87 % of the saturation tilt angle (51.8 degrees). On the other hand, the liquid crystal device B-0 was leftstanding for 500 hours under no voltage application.

[0104] Thereafter, these liquid crystal devices B-0 and B-1 were subjected to evaluation of V-T characteristic at 30 °C by using a triangular wave (0 - ± 5 volts, 0.1 Hz).

[0105] V-T curves for the liquid crystal device B-1 (solid line) and the liquid crystal device B-0 (dotted line) are shown in Figure 12.

[0106] As shown in Figure 12, the two V-T curves for the liquid crystal devices B-0 and B-1 were close to each other and merely provided a maximum difference in transmittance of ca. 4.5 %.

Comparative Example 2

[0107] Two active matrix-type liquid crystal devices B-2 (for continuous voltage application) and B-0 (for continuous no voltage application) were prepared and evaluated in the same manner as in Example 3 except that the maximum Vop value (6 volts) was changed to 12 volts (for the device B-2) providing a maximum tilt angle of 51.8 degrees (100 % of the saturation tilt angle (51.8 degrees)).

[0108] The results are shown in Figure 13.

[0109] The resultant V-T curves for the liquid crystal device B-2 (solid line) and the liquid crystal device B-0 (dotted line) merely provided a maximum difference in voltage for giving identical luminance (transmittance) of ca. 300 mV.

[0110] As described hereinabove, according to embodiments of the invention, by driving an active matrix-type chiral smectic liquid crystal device under such a condition that a maximum tilt angle of a liquid crystal at the time of actual drive is below (preferably at most 95 % of) a saturation tilt angle, it becomes possible to prevent deterioration in display characteristic due to burning phenomenon and/or change in alignment state even in a long-term drive, thus stably realizing good analog gradation display for a long time.

Claims

1. A driving method for a liquid crystal device of the type comprising a pair of oppositely disposed substrates each provided with an electrode, a chiral smectic liquid crystal disposed between the substrates to form a plurality of pixels, and a plurality of active elements each of which is provided to an associated pixel and is connected with an associated electrode so as to effect a matrix drive of the liquid crystal device, the liquid crystal being placed in

a monostable state under no voltage application; said method comprising:

a step of driving the liquid crystal device so that the liquid crystal is tilted from the monostable state to provide a maximum tilt angle in actual drive smaller than a saturation tilt angle.

- 5 **2.** A method according to Claim 1, wherein the maximum tilt angle is at most 95 % of the saturation tilt angle.
- 3.** A method according to Claim 1, wherein the maximum tilt angle is at most 90 % of the saturation tilt angle.
- 4.** A method according to Claim 1, wherein the maximum tilt angle is at most 80 % of the saturation tilt angle.
- 10 **5.** A method according to any one of Claims 1 - 4, wherein the liquid crystal device provides a V-shaped voltage-transmittance curve being symmetrical with respect to an axis for representing a transmittance.
- 6.** A method according to any one of Claims 1 - 4, wherein the liquid crystal device provides a Half V-shaped voltage-transmittance curve being asymmetrical with respect to an axis for representing a transmittance.
- 15 **7.** A method according to any one of Claims 1 - 4, wherein the saturation tilt angle is at least 45 degrees.
- 8.** A method according to Claim 5, wherein the saturation tilt angle is at least 45 degrees.
- 20 **9.** A method according to claim 6, wherein the saturation tilt angle is at least 45 degrees.

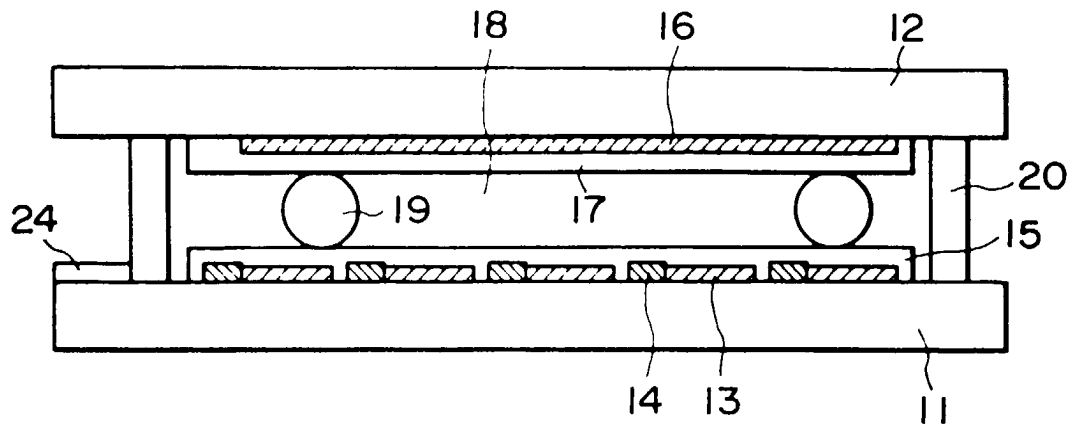


FIG. 1

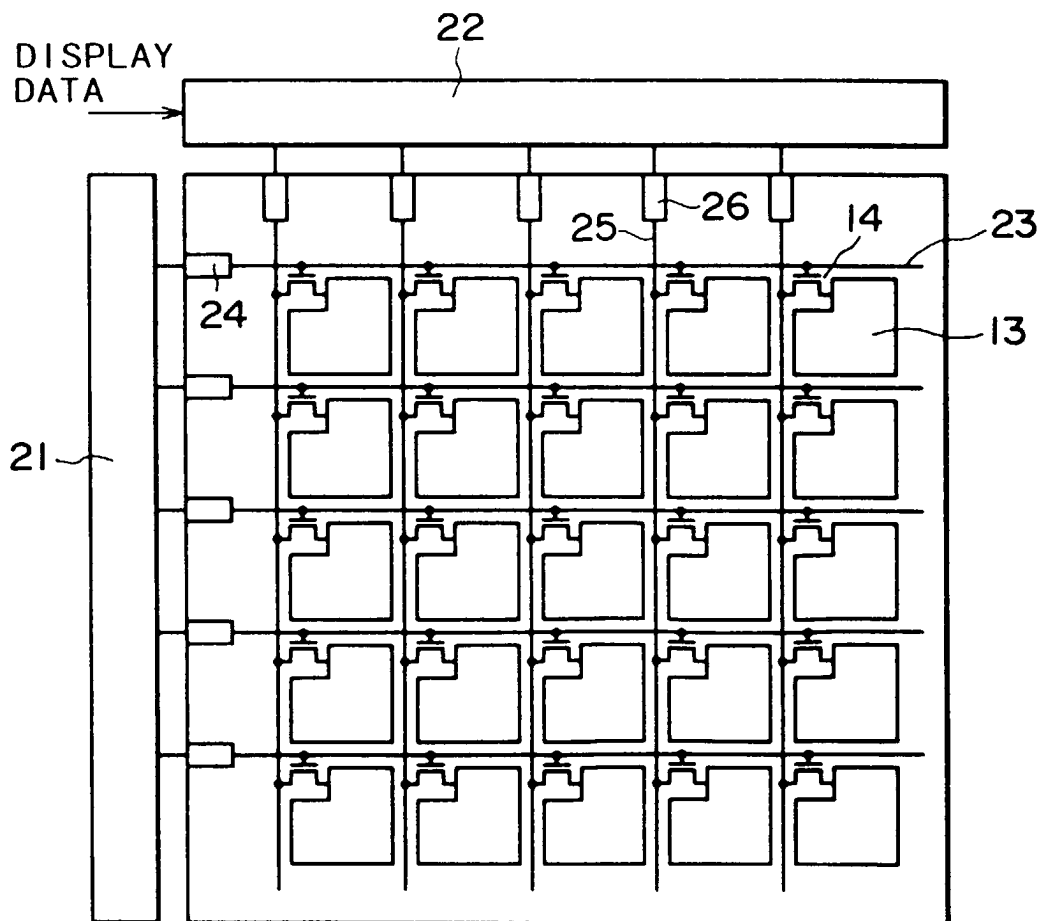


FIG. 2

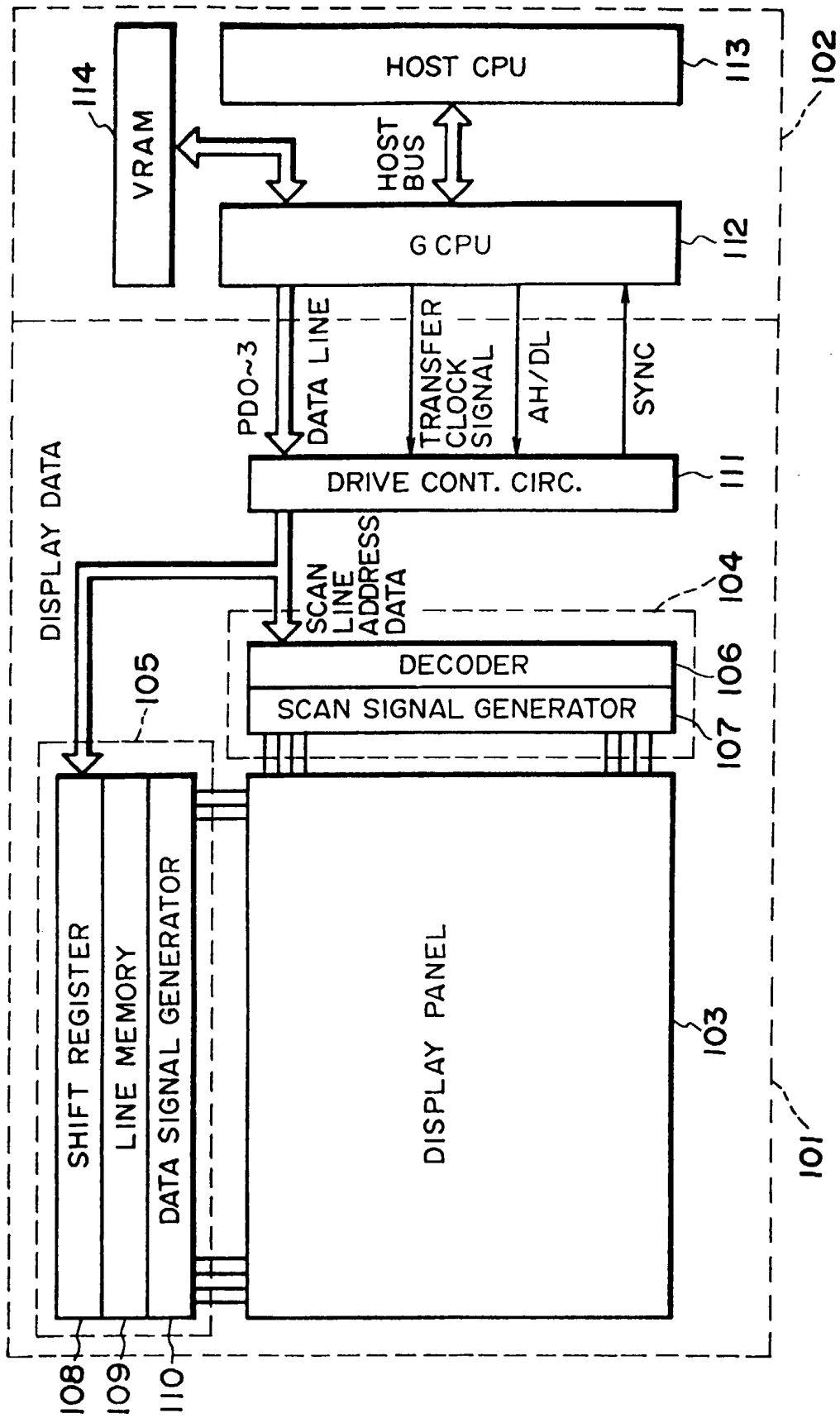


FIG. 3

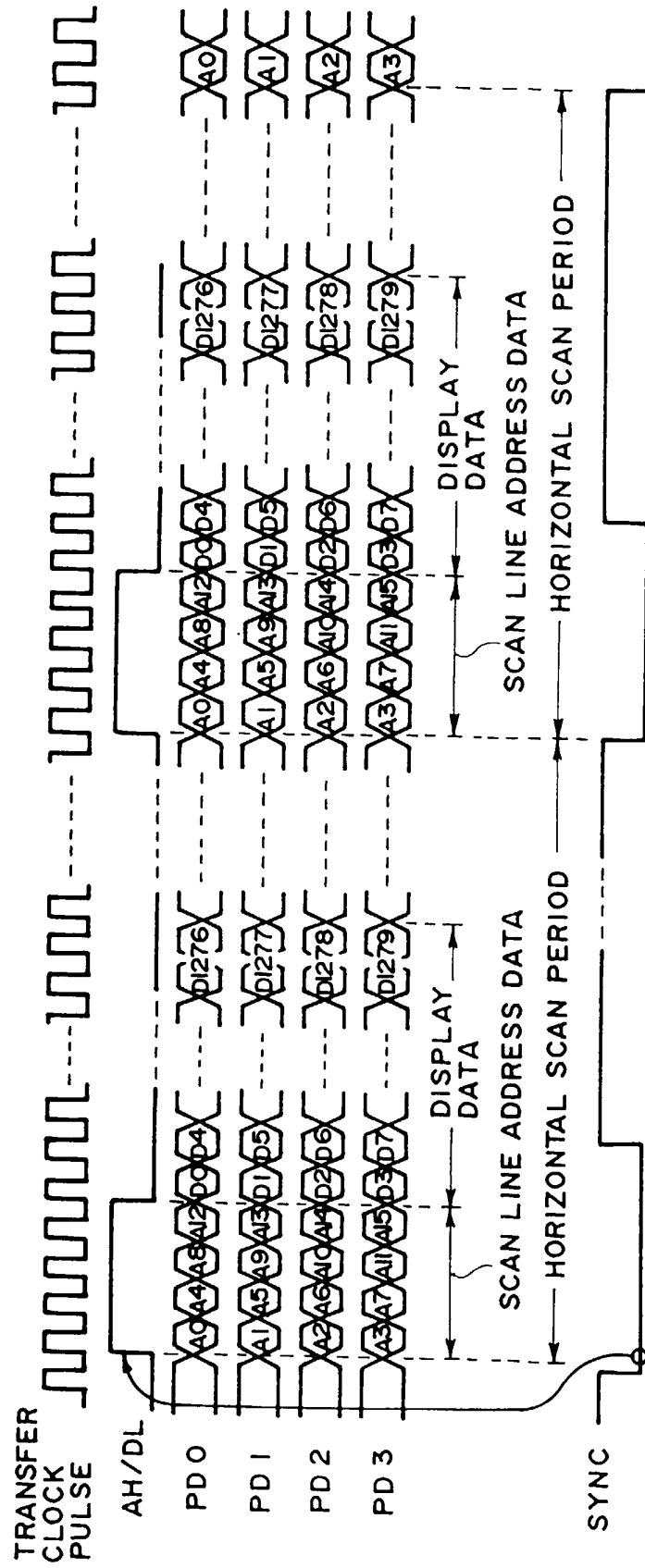


FIG. 4

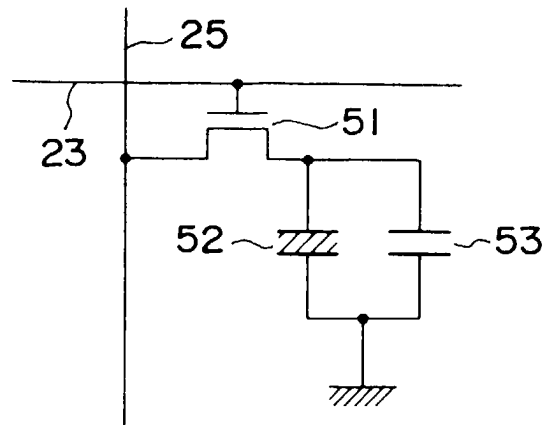


FIG. 5

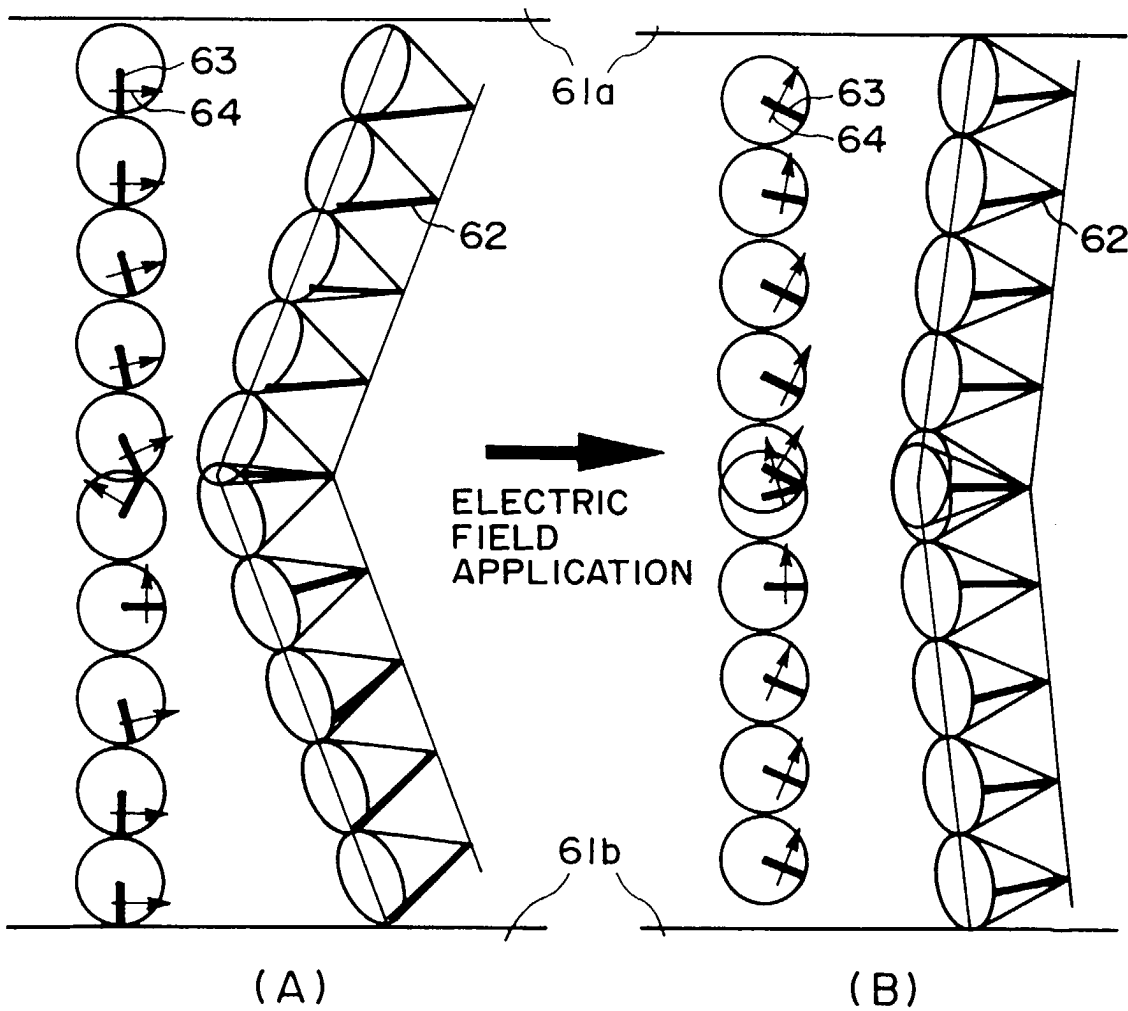


FIG. 6

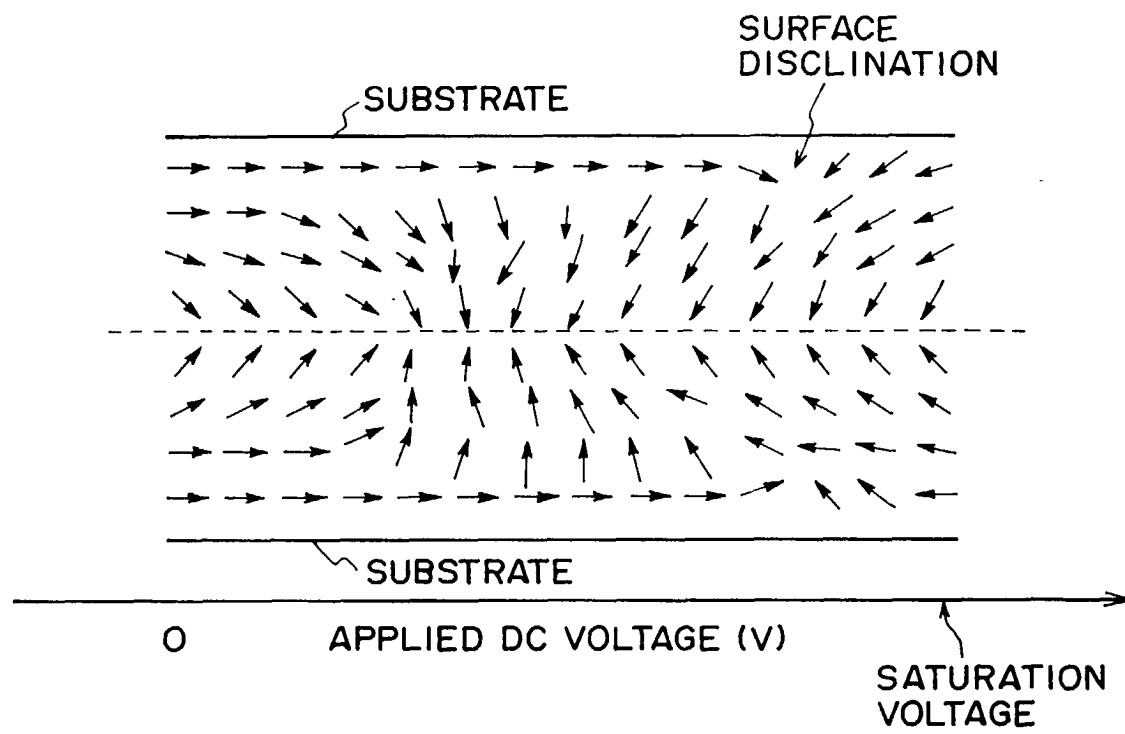


FIG. 7

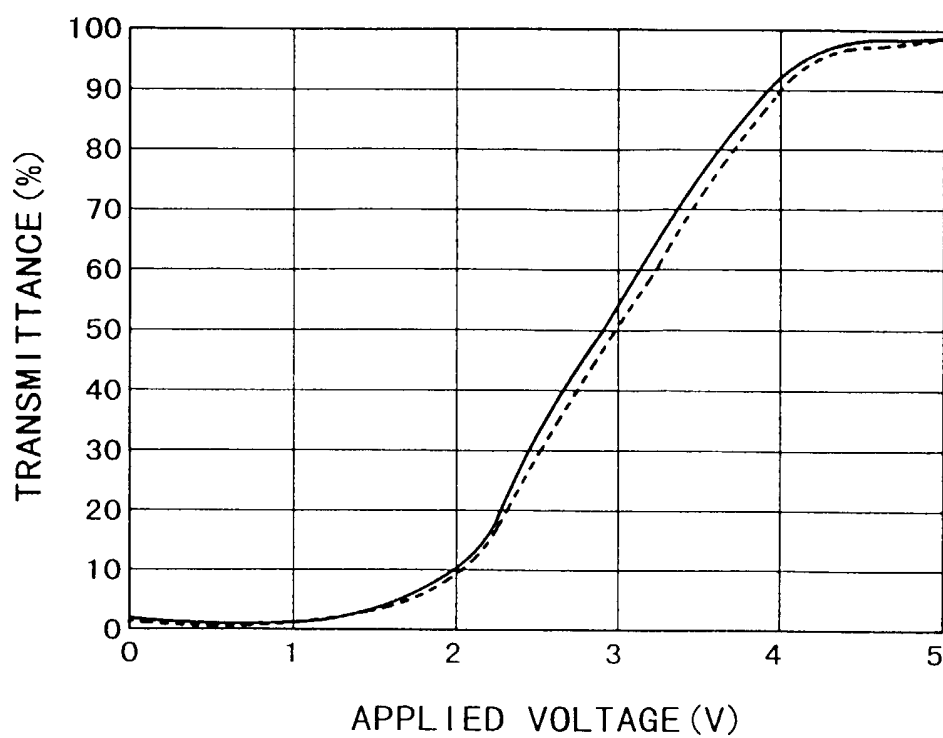


FIG. 8

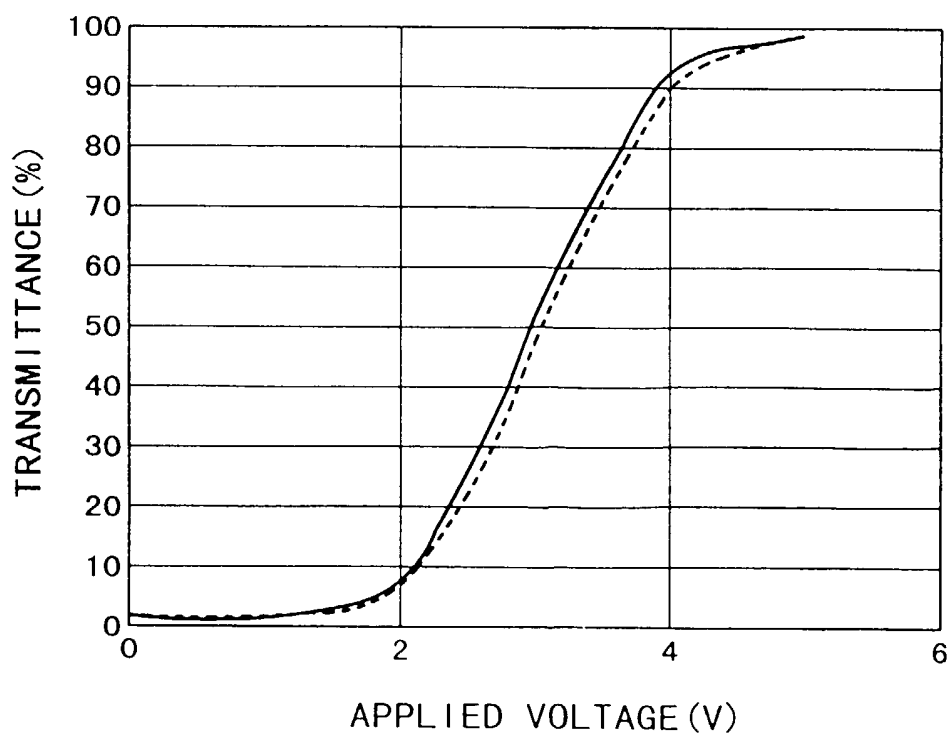


FIG. 9

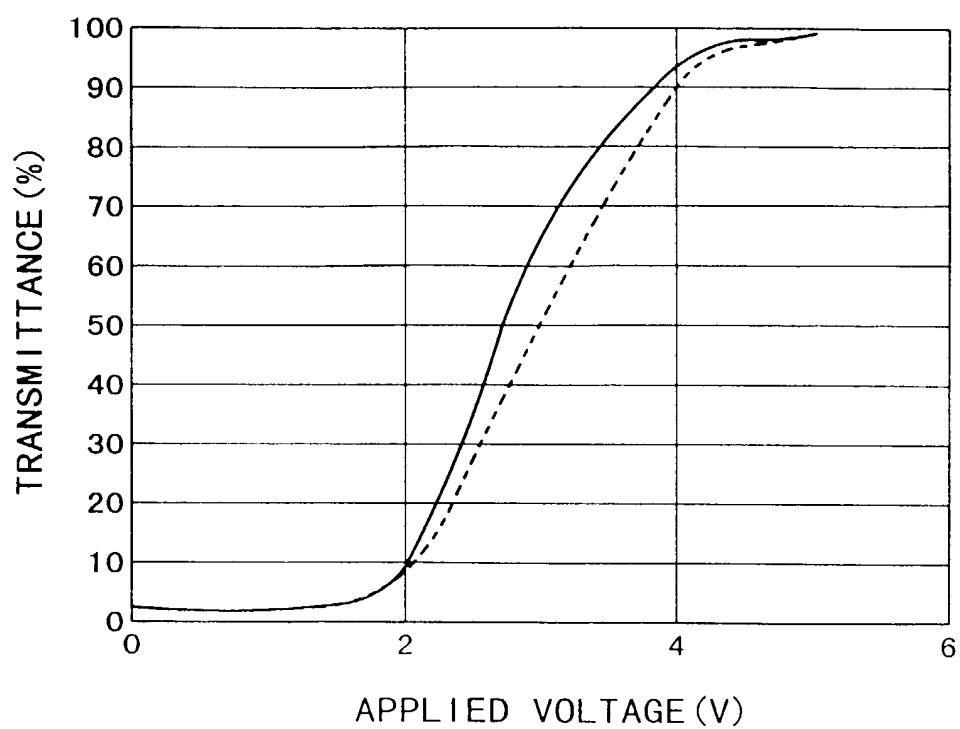


FIG. 10

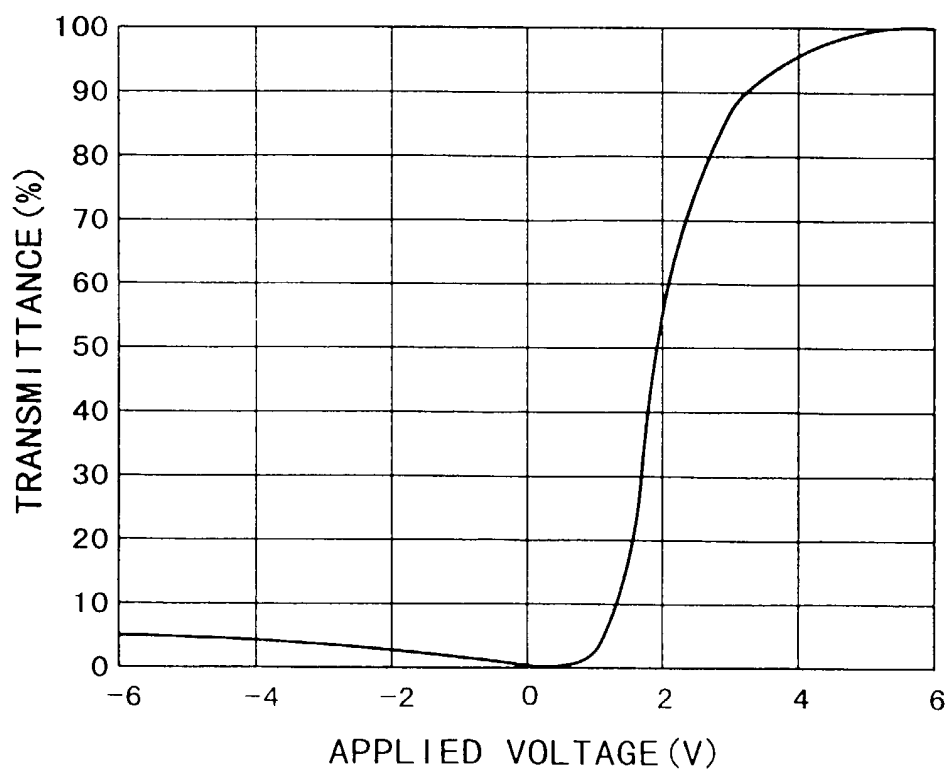


FIG. 11

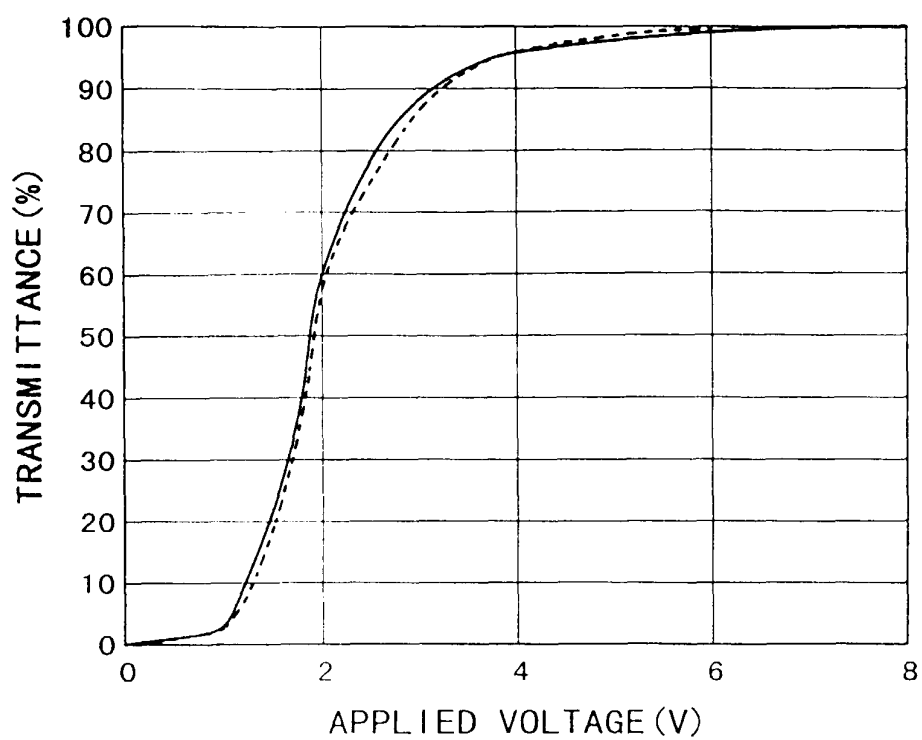


FIG. 12

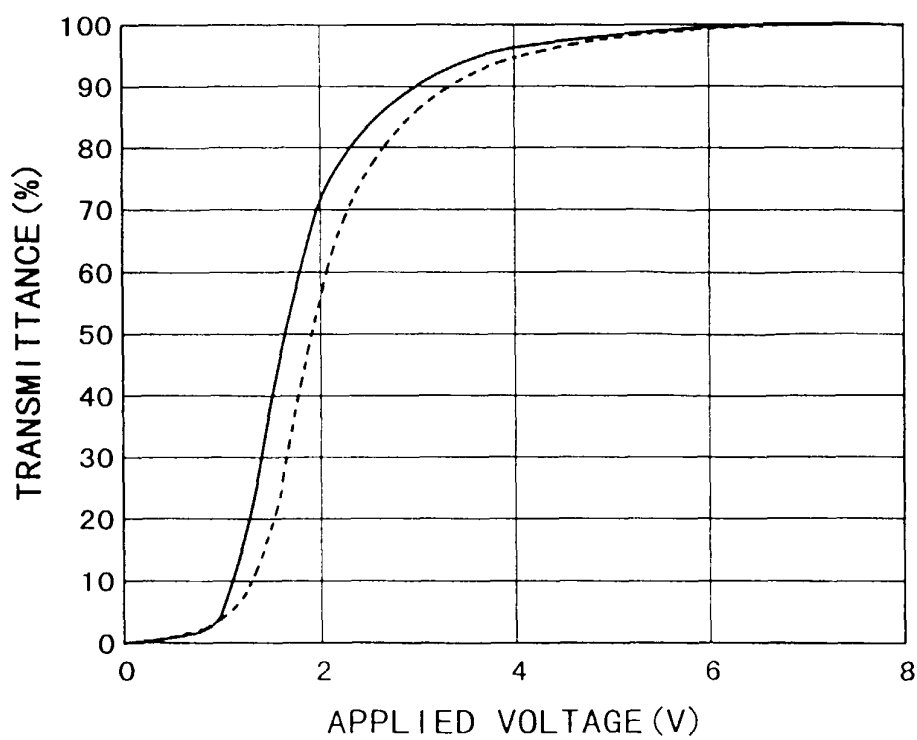


FIG. 13

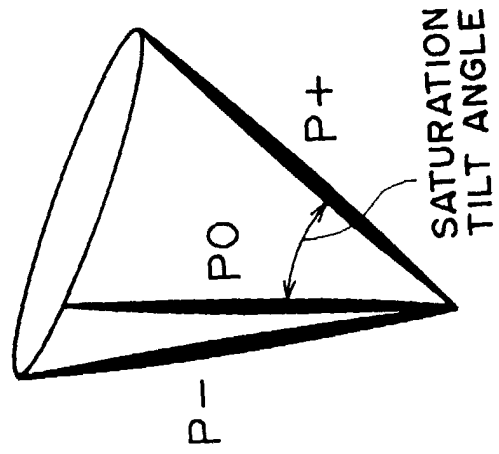


FIG. 14B

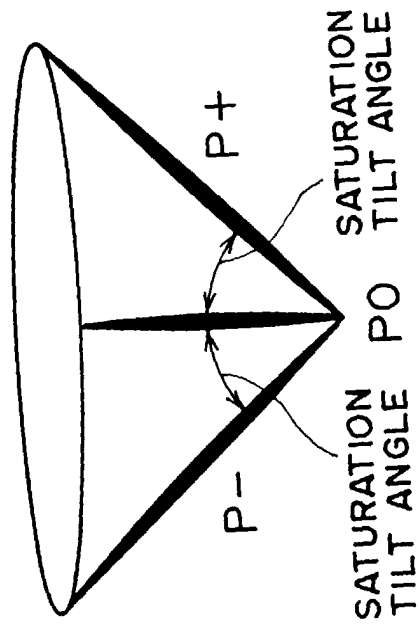


FIG. 14A