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**Choi et al.**(10) **Pub. No.: US 2009/0102993 A1**(43) **Pub. Date: Apr. 23, 2009**(54) **LIQUID CRYSTAL DISPLAY DEVICE OF  
IN-PLANE SWITCHING MODE, METHOD OF  
FABRICATING THE SAME, AND METHOD  
OF DRIVING THE SAME**(30) **Foreign Application Priority Data**

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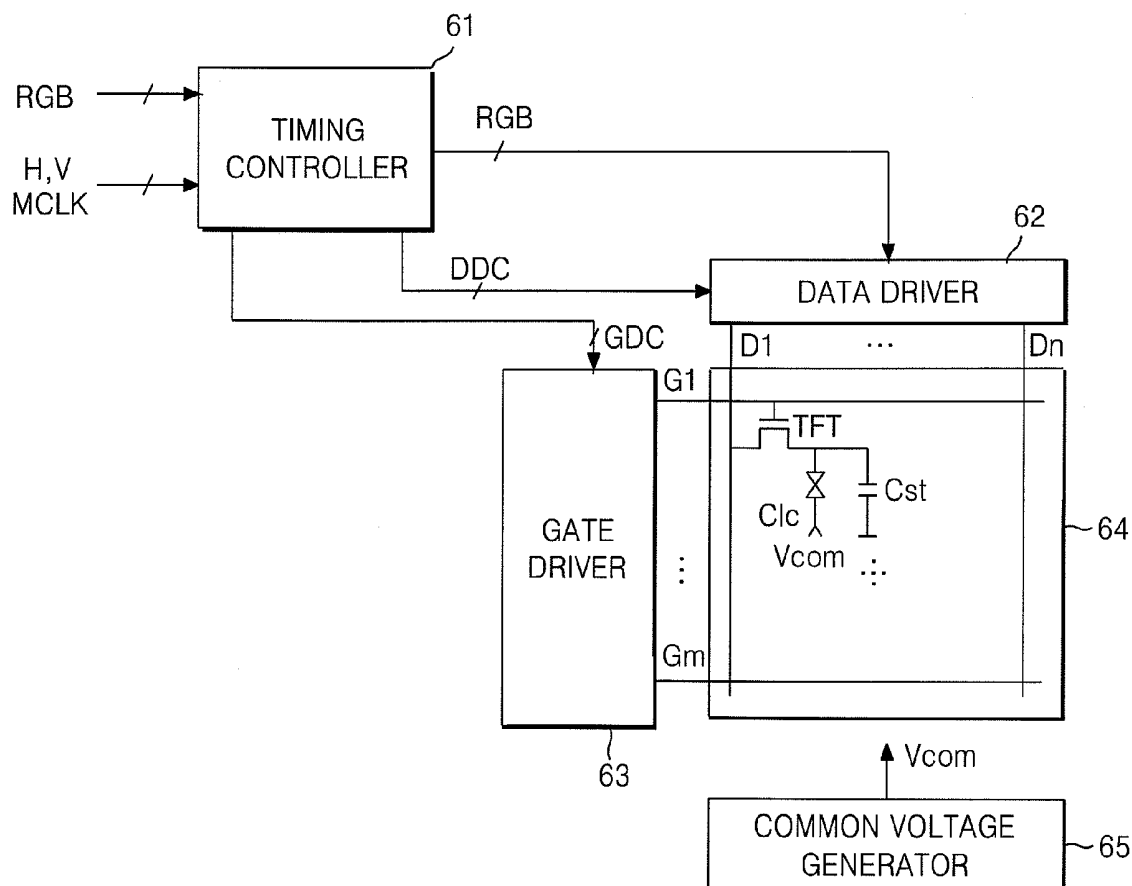
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**G02F 1/1337** (2006.01)(52) **U.S. Cl.** ..... **349/37; 349/187**(57) **ABSTRACT**

An in-plane switching mode liquid crystal display device includes upper and lower substrates, first and second ferroelectric liquid crystal layers, a nematic system crystal layer, and first and second electrodes. The electrodes and liquid crystal layers are located between the substrates, with the nematic liquid crystal layer between the ferroelectric liquid crystal layers. The ferroelectric liquid crystal layers have different spontaneous polarization directions. An electric field is applied to the liquid crystal layers using the electrodes. The ferroelectric liquid crystal layers react to different electric field to conduct an in-plane driving of liquid crystal molecules in the nematic liquid crystal layer.

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(62) Division of application No. 11/091,199, filed on Mar. 28, 2005.



# FIG. 1

## RELATED ART

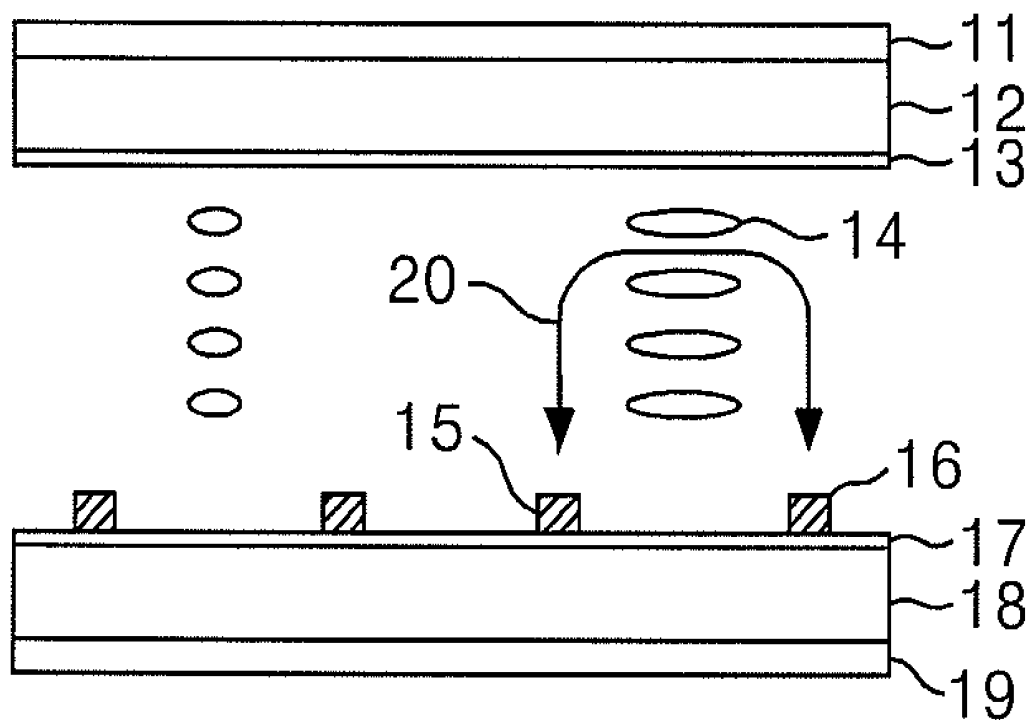


FIG. 2A  
RELATED ART

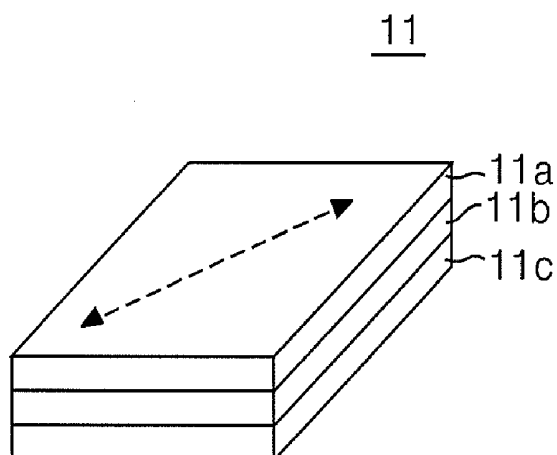


FIG. 2B  
RELATED ART

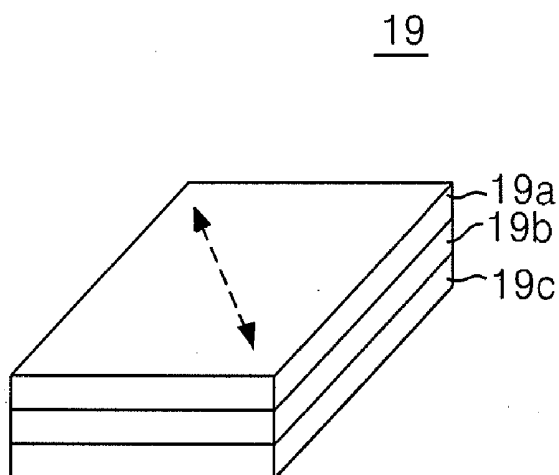
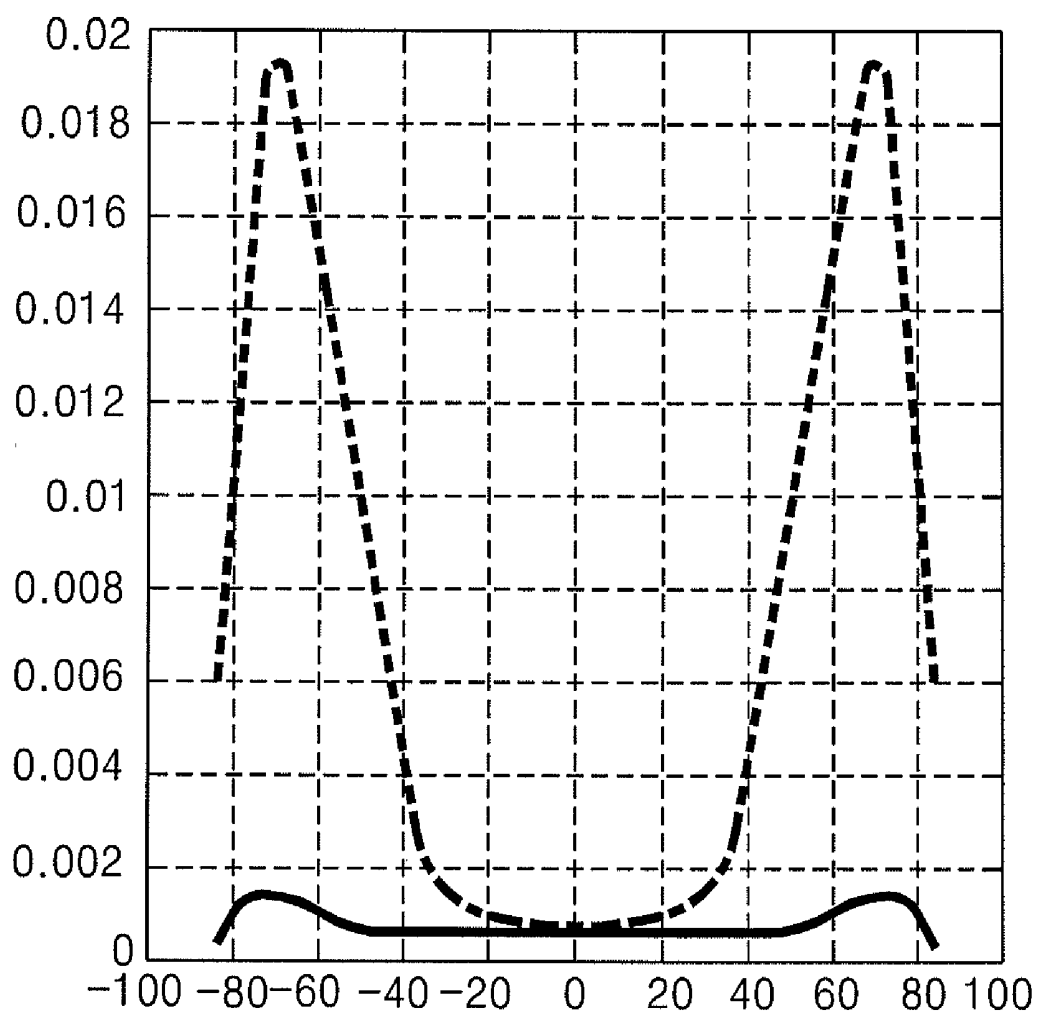
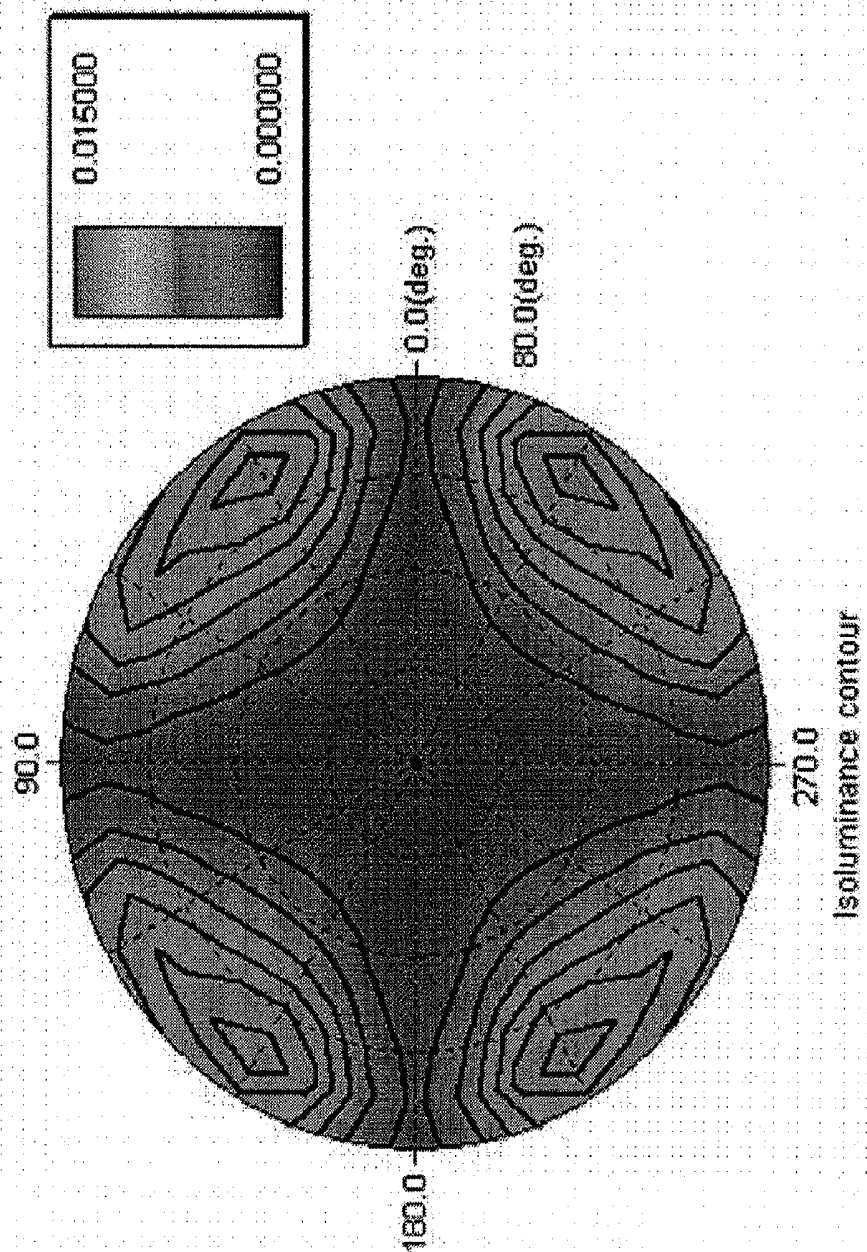


FIG. 3  
RELATED ART



----- BEFORE USING COMPENSATION FILM  
———— AFTER USING COMPENSATION FILM

FIG. 4  
RELATED ART



# FIG. 5

## RELATED ART

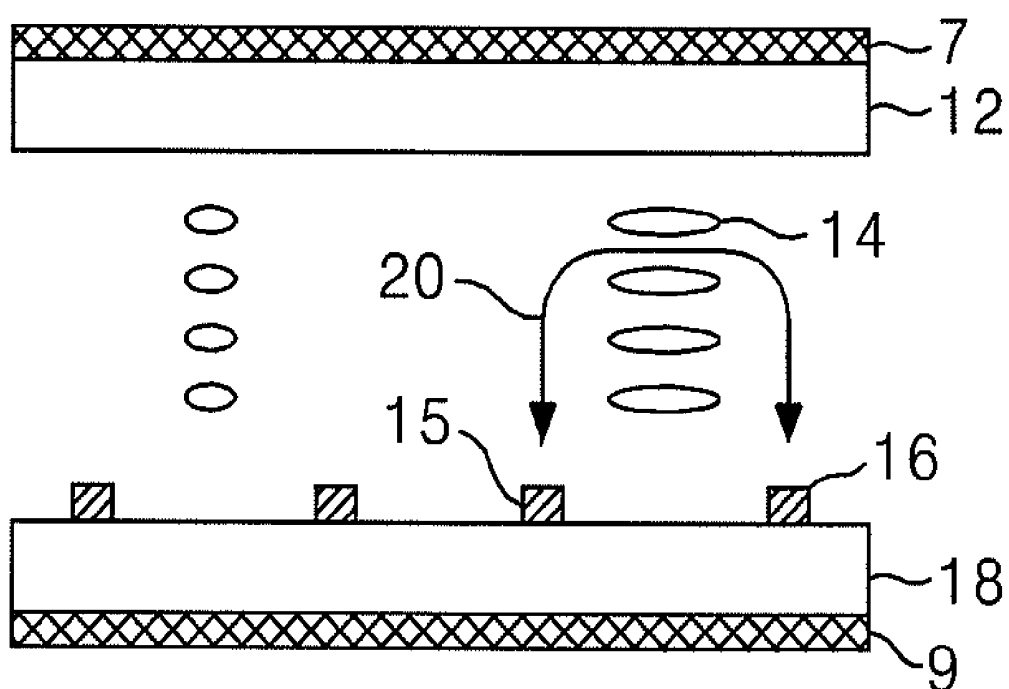


FIG. 6  
RELATED ART

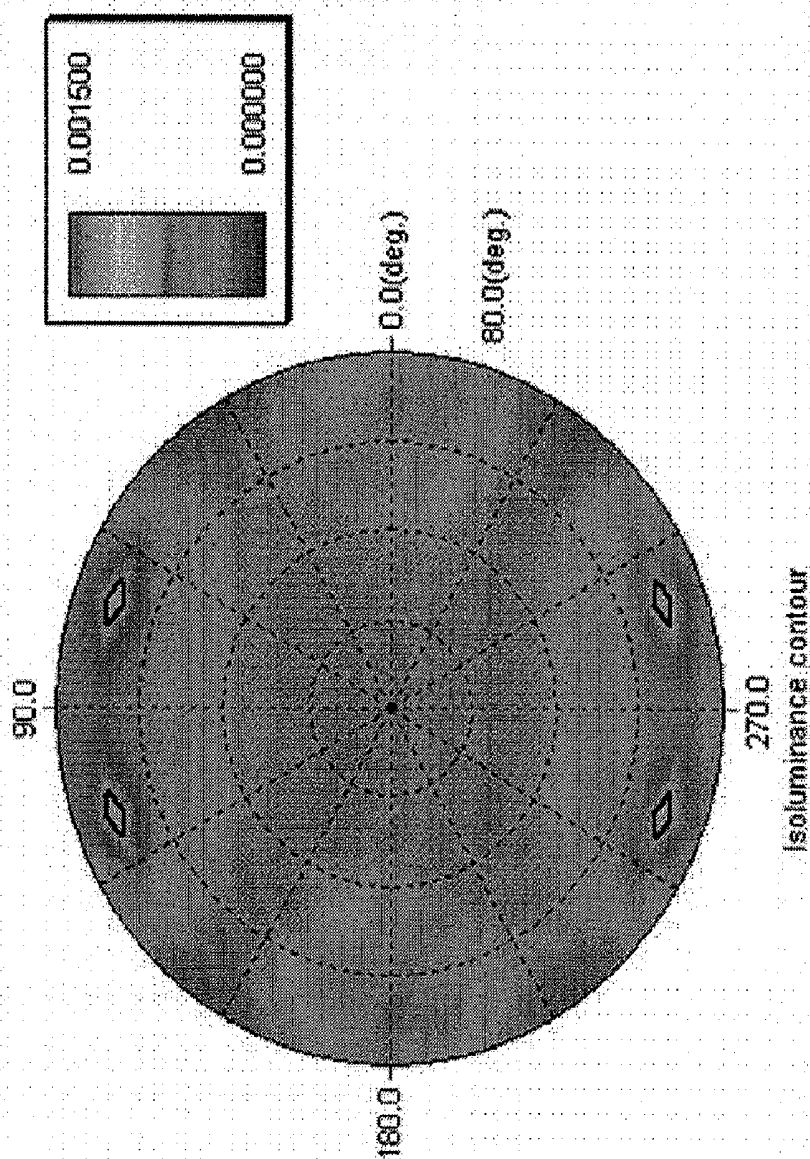


FIG. 7

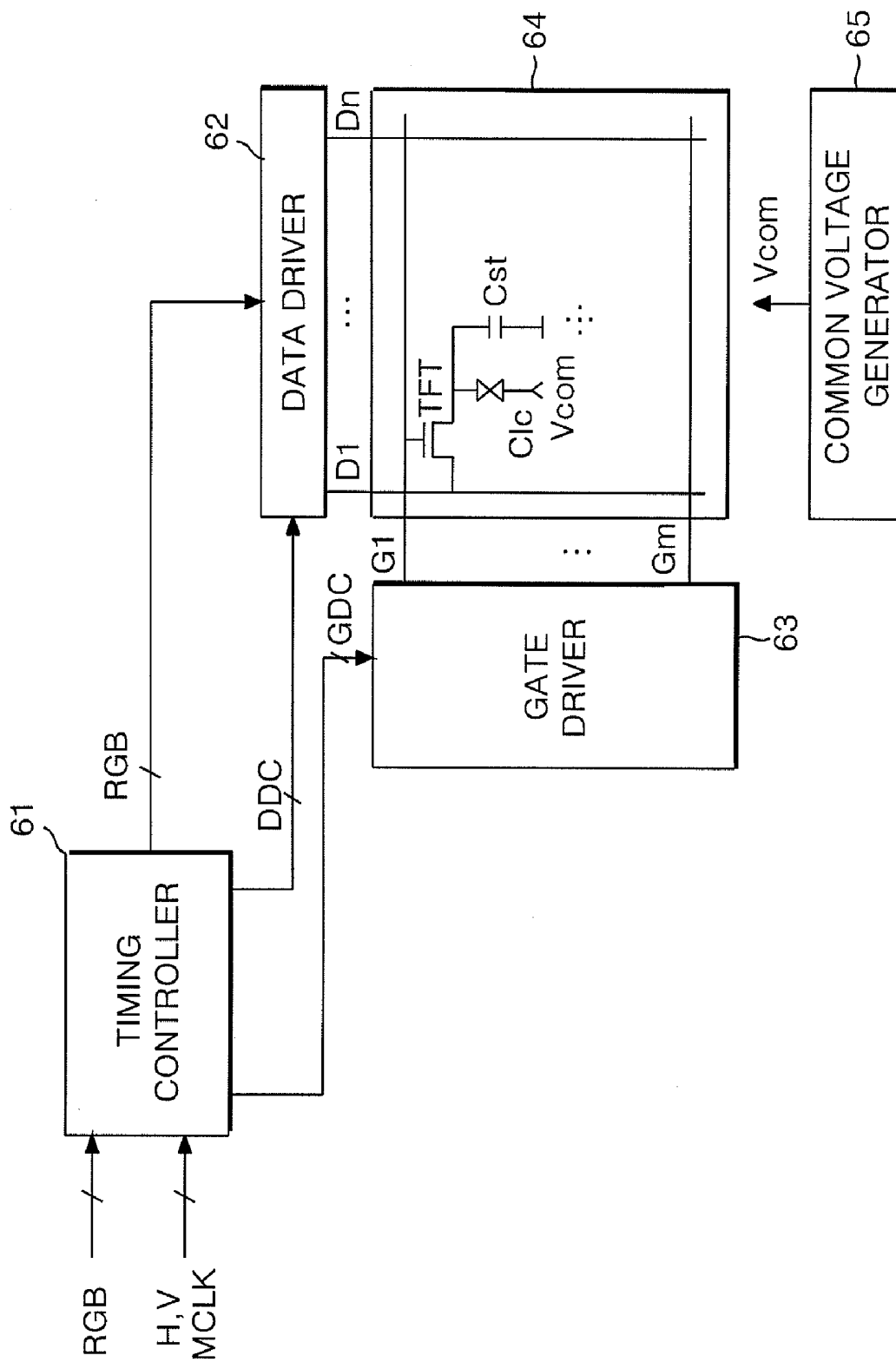


FIG. 8

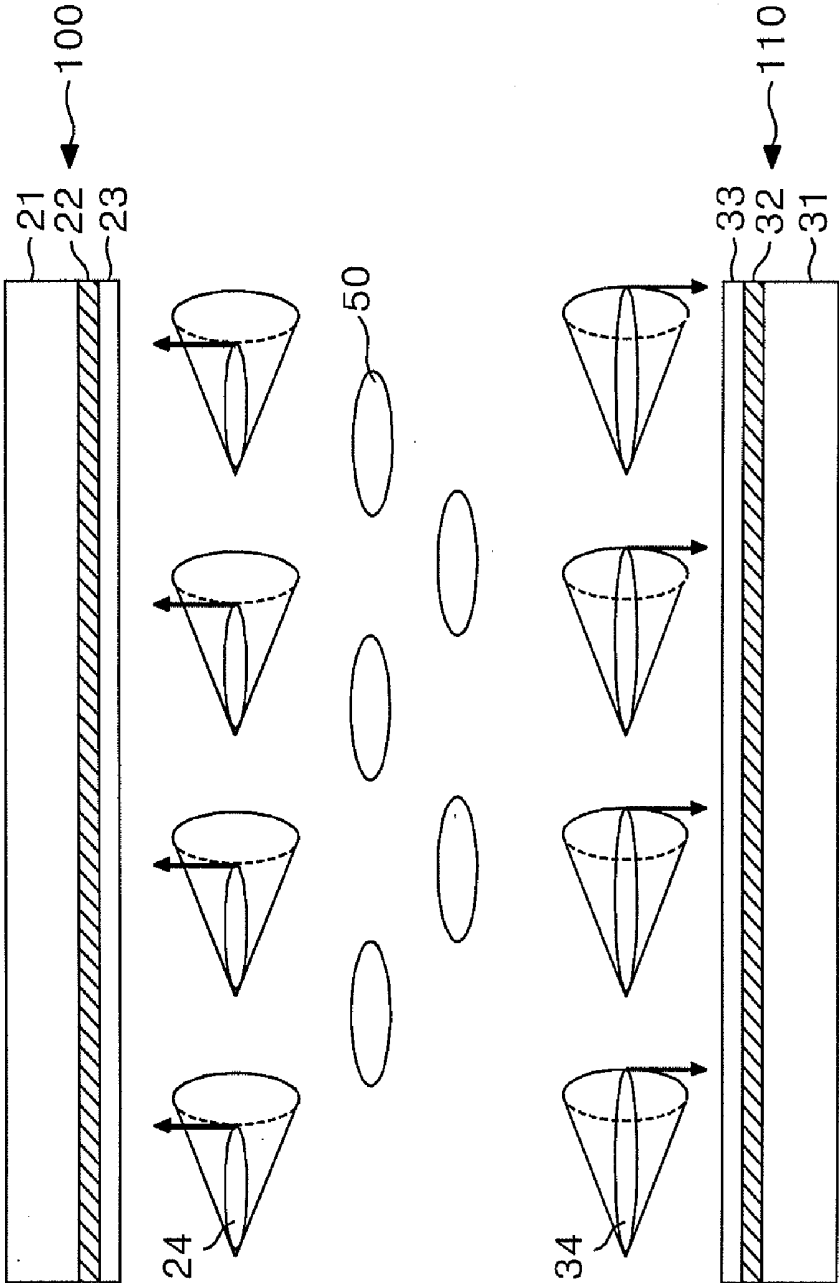


FIG. 9

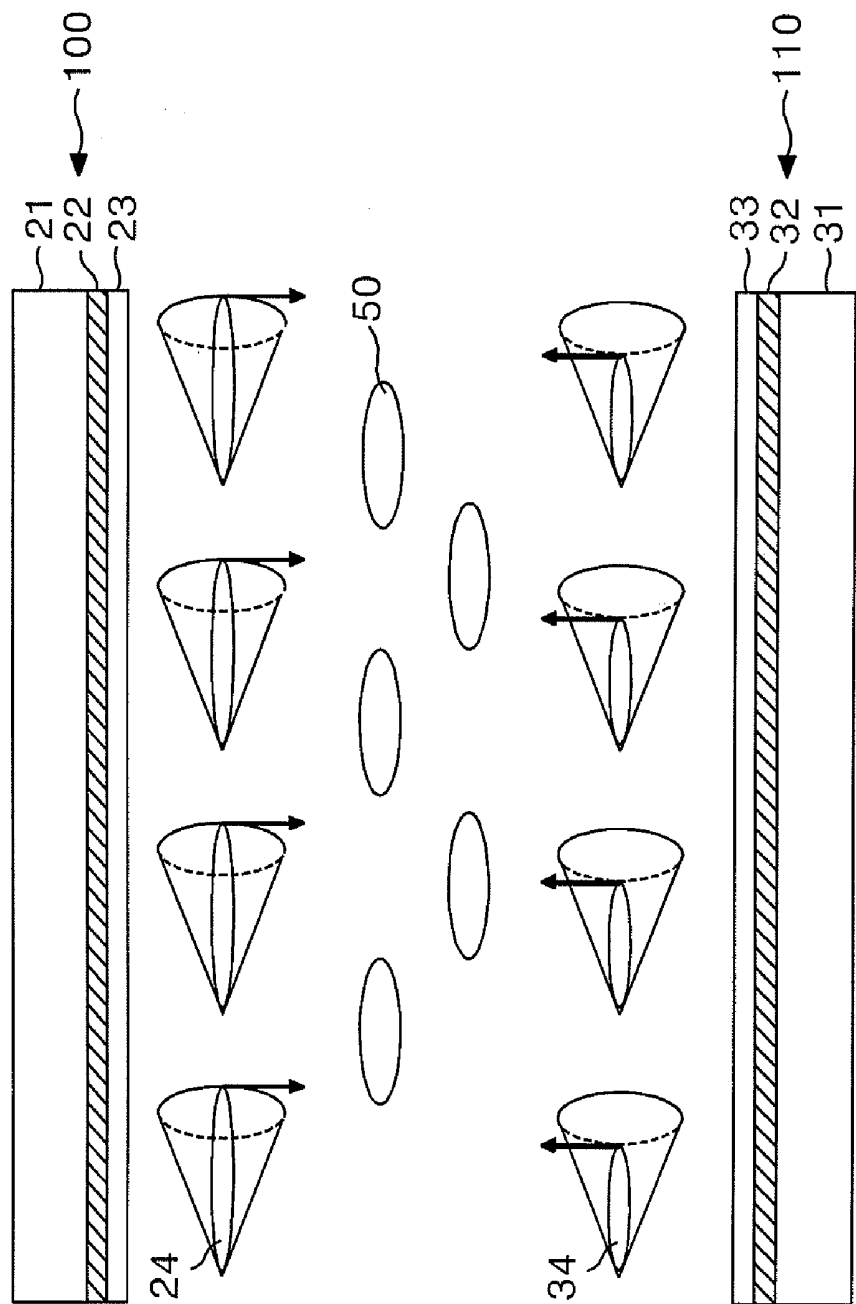


FIG. 10

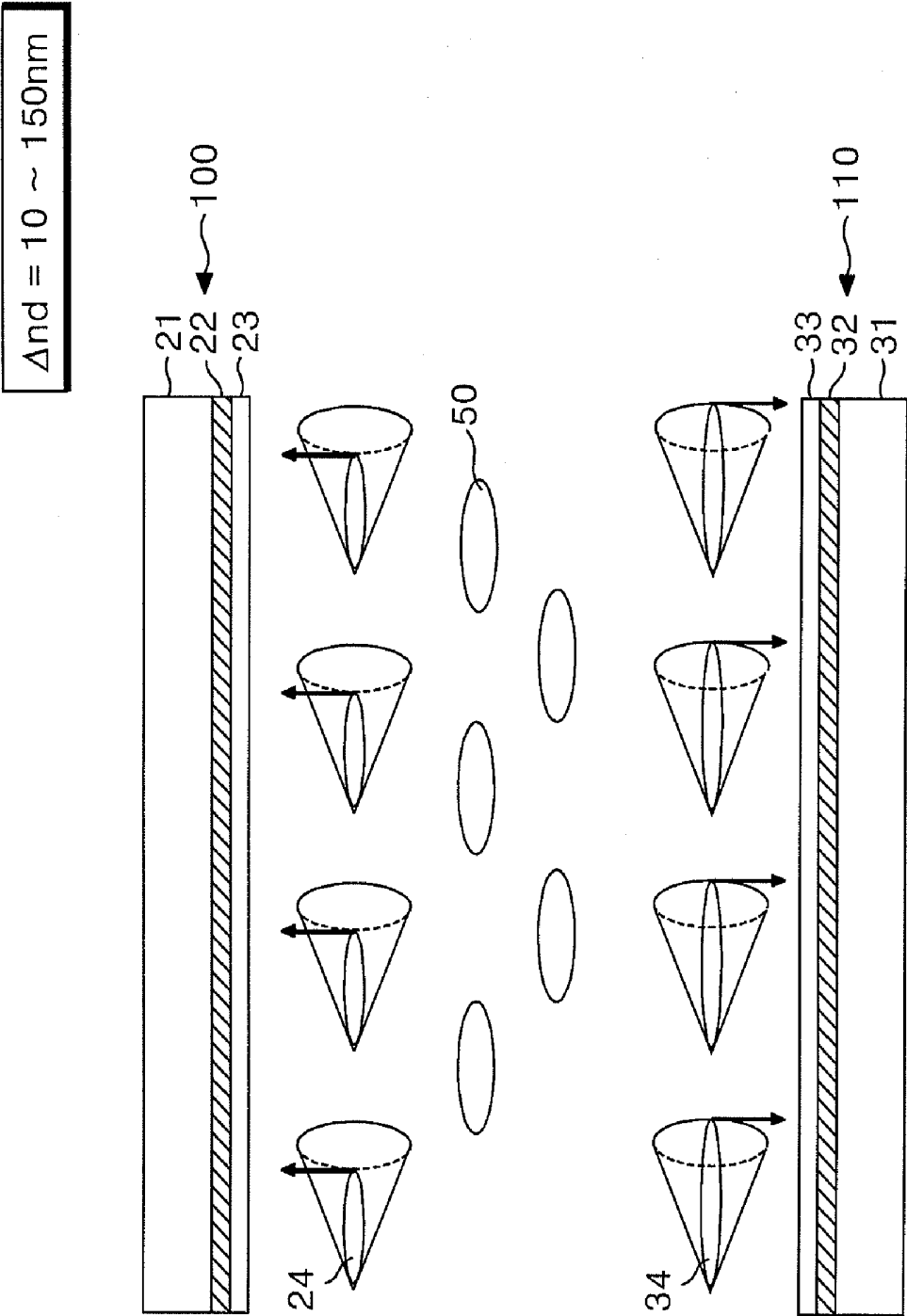


FIG. 11A

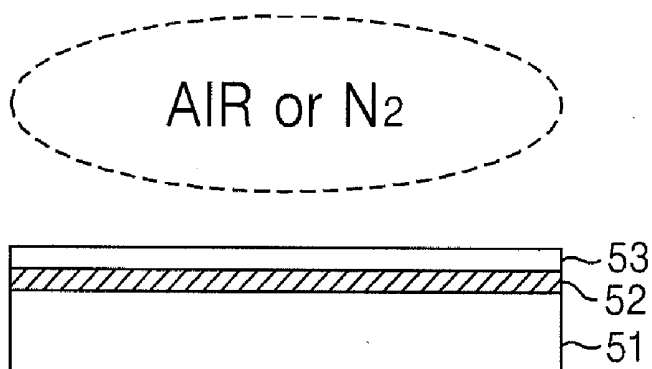


FIG. 11B

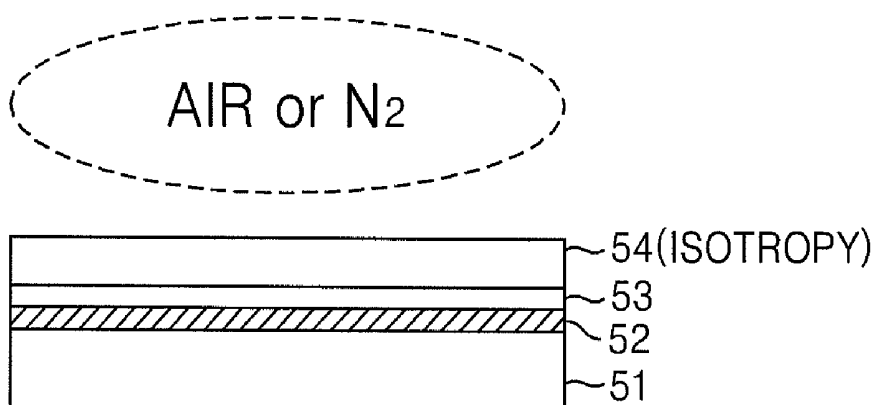


FIG.11C

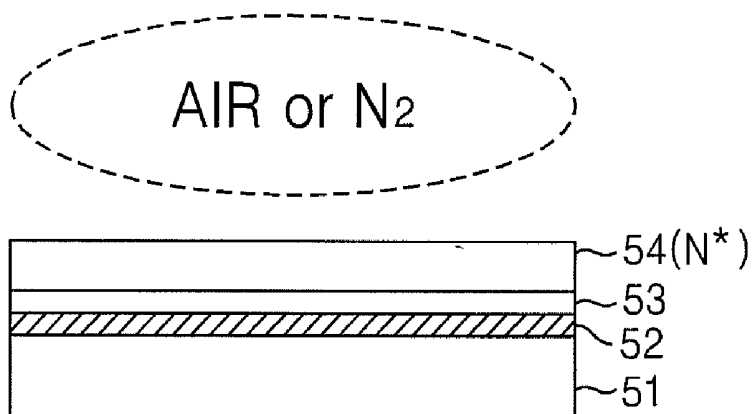


FIG.11D

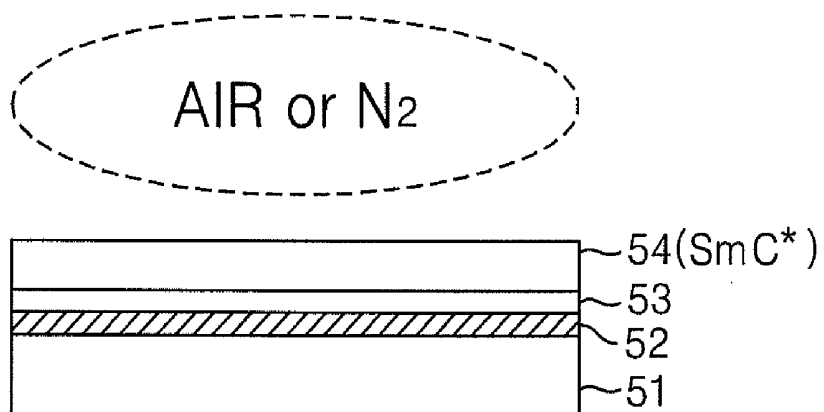


FIG.12

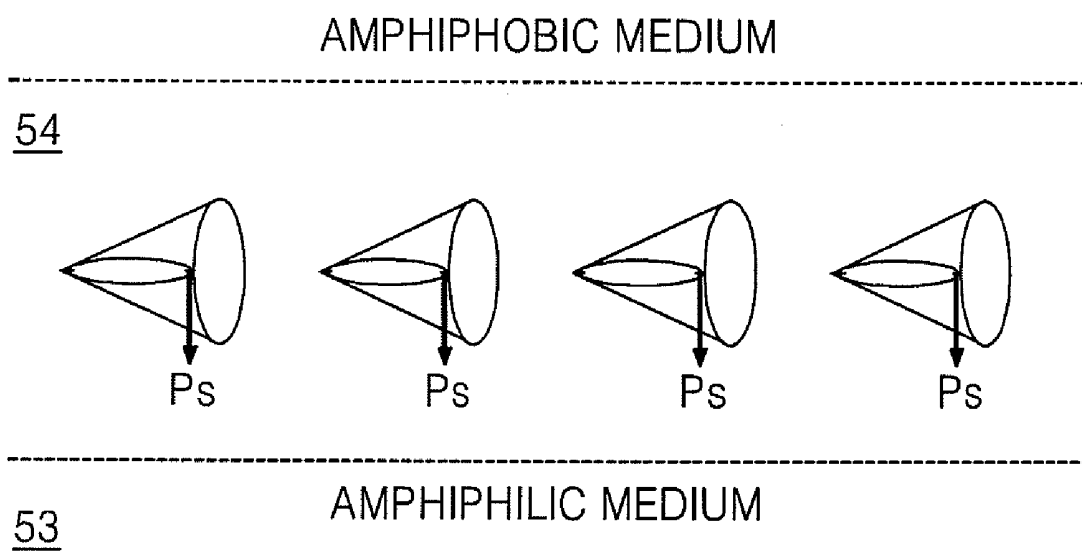


FIG. 13A

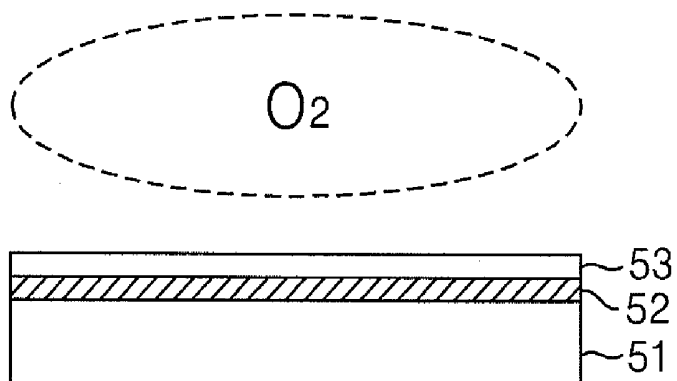


FIG. 13B

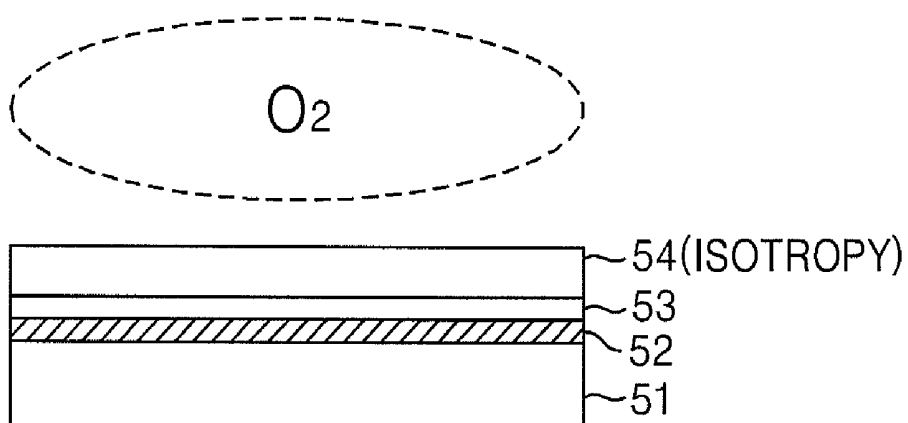


FIG. 13C

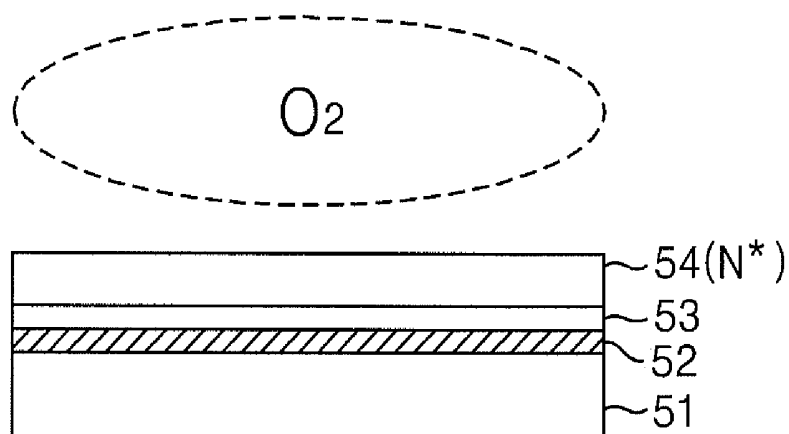


FIG. 13D

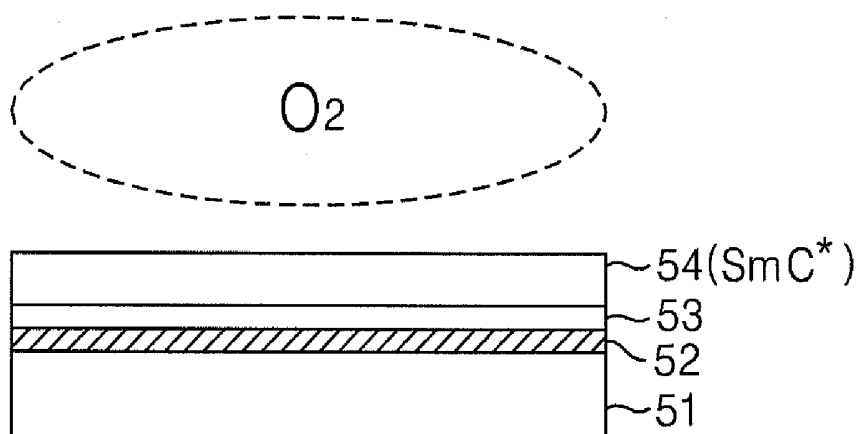


FIG.14

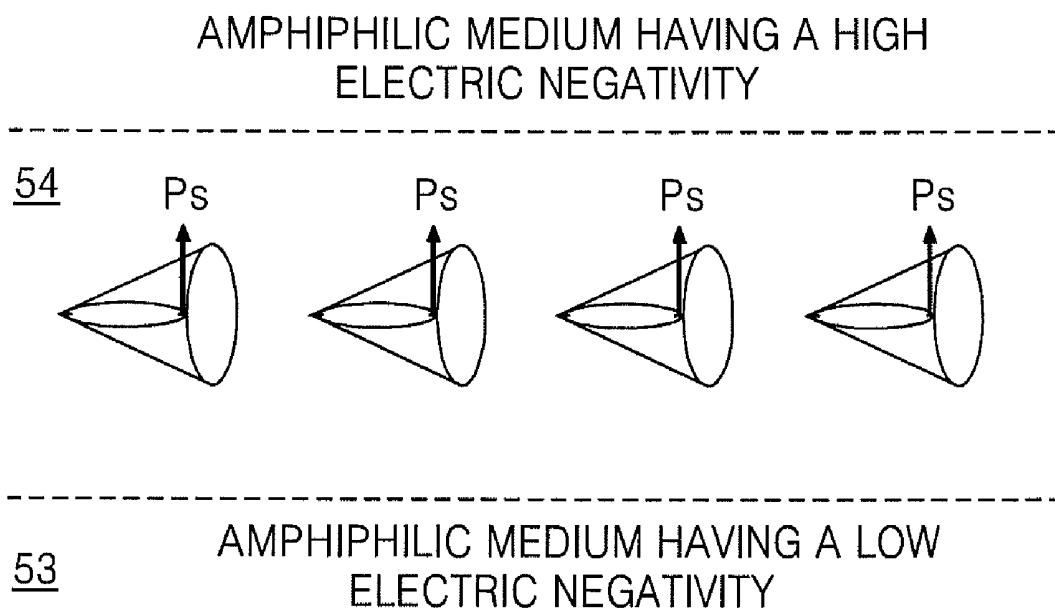


FIG. 15A

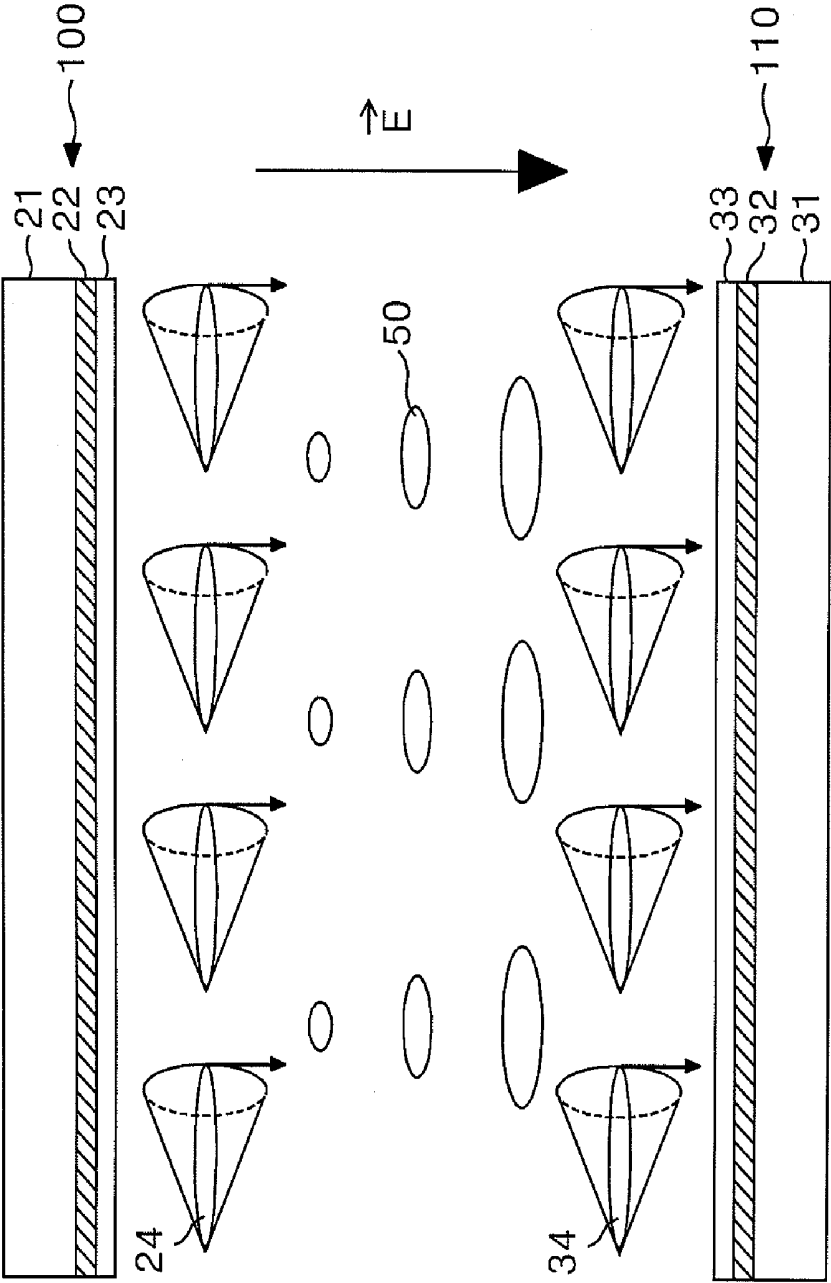


FIG. 15B

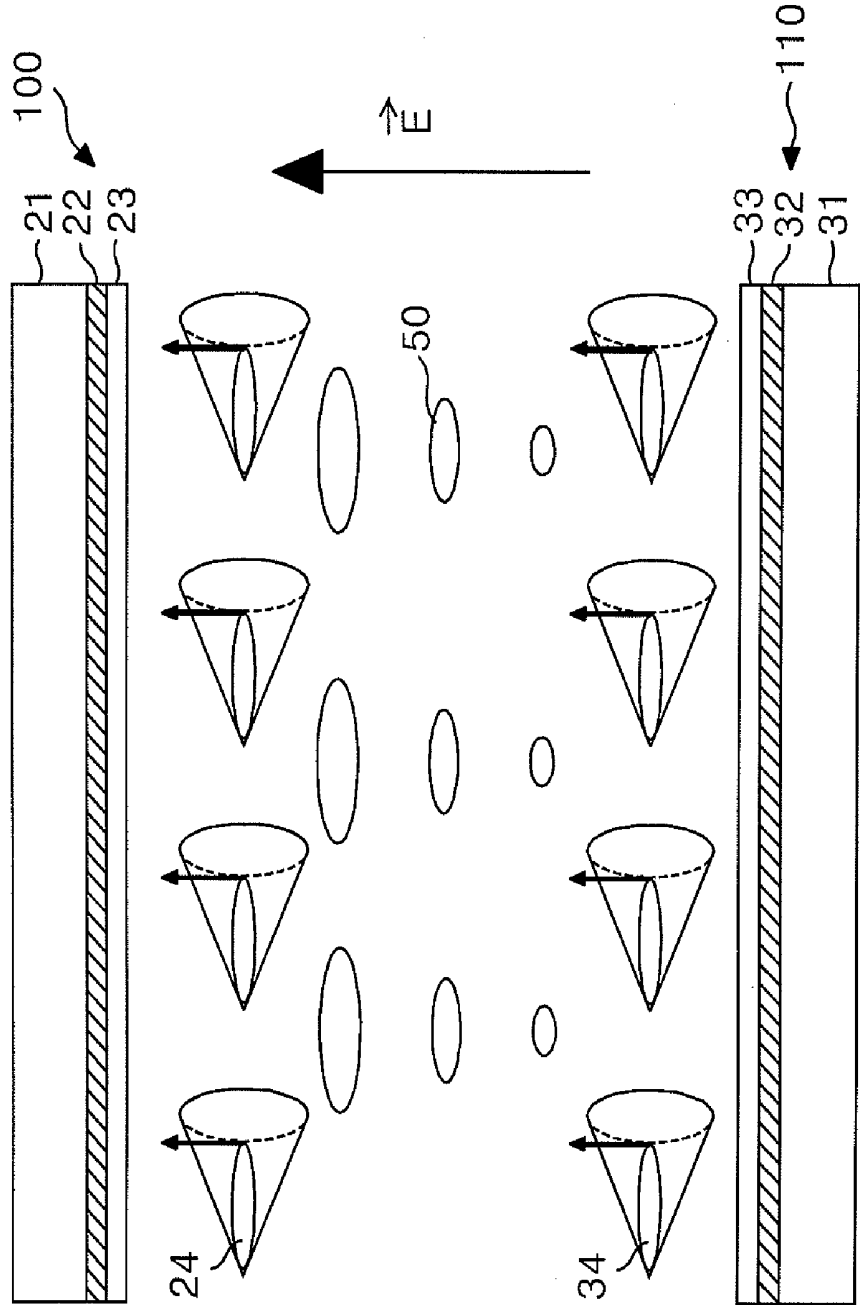
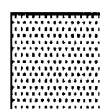
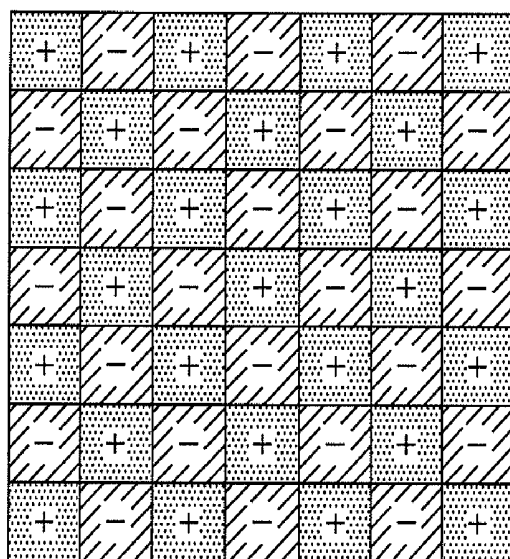
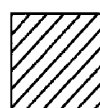


FIG.16

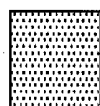
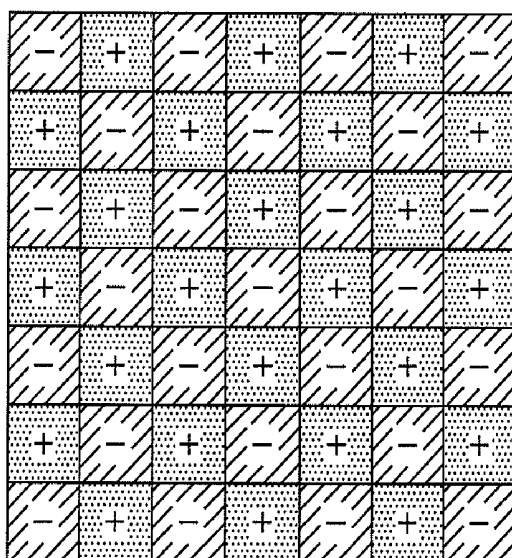


LIGHT TRANSMISSION

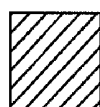


LIGHT INTERCEPTION

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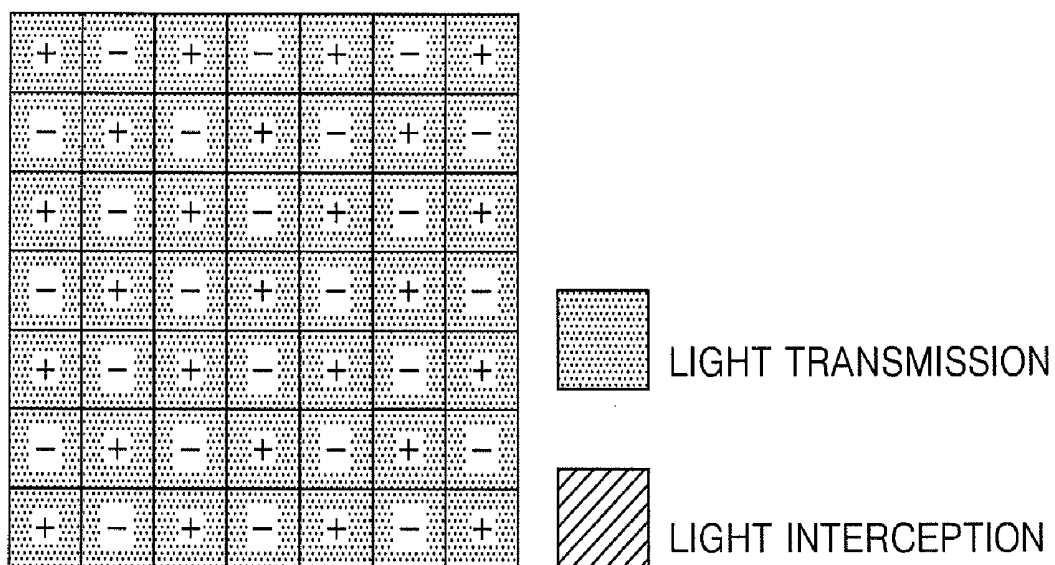
LIGHT TRANSMISSION



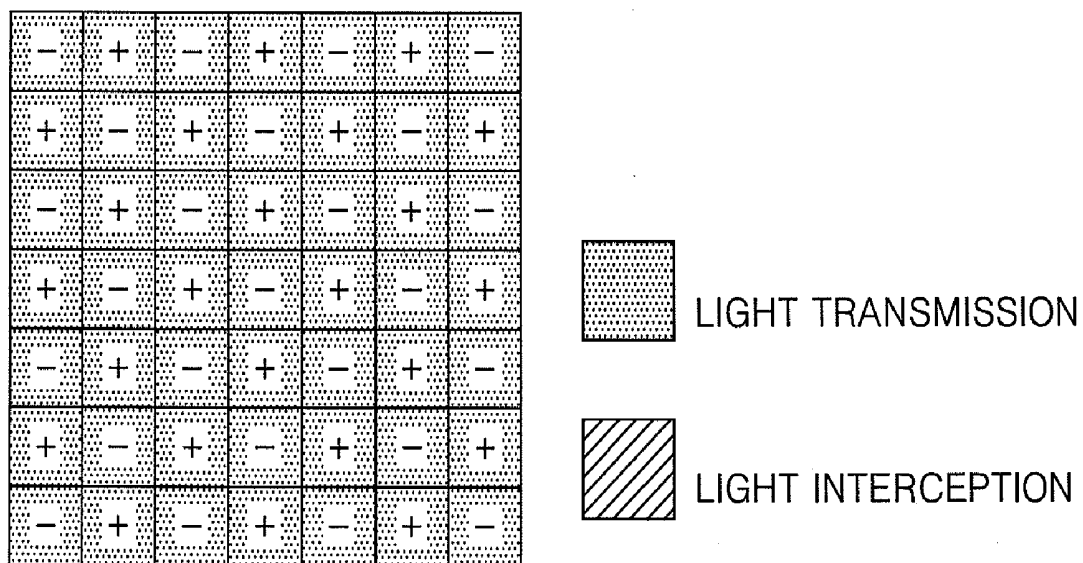
LIGHT INTERCEPTION

<EVEN FRAME>

FIG. 17



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FIG. 18A

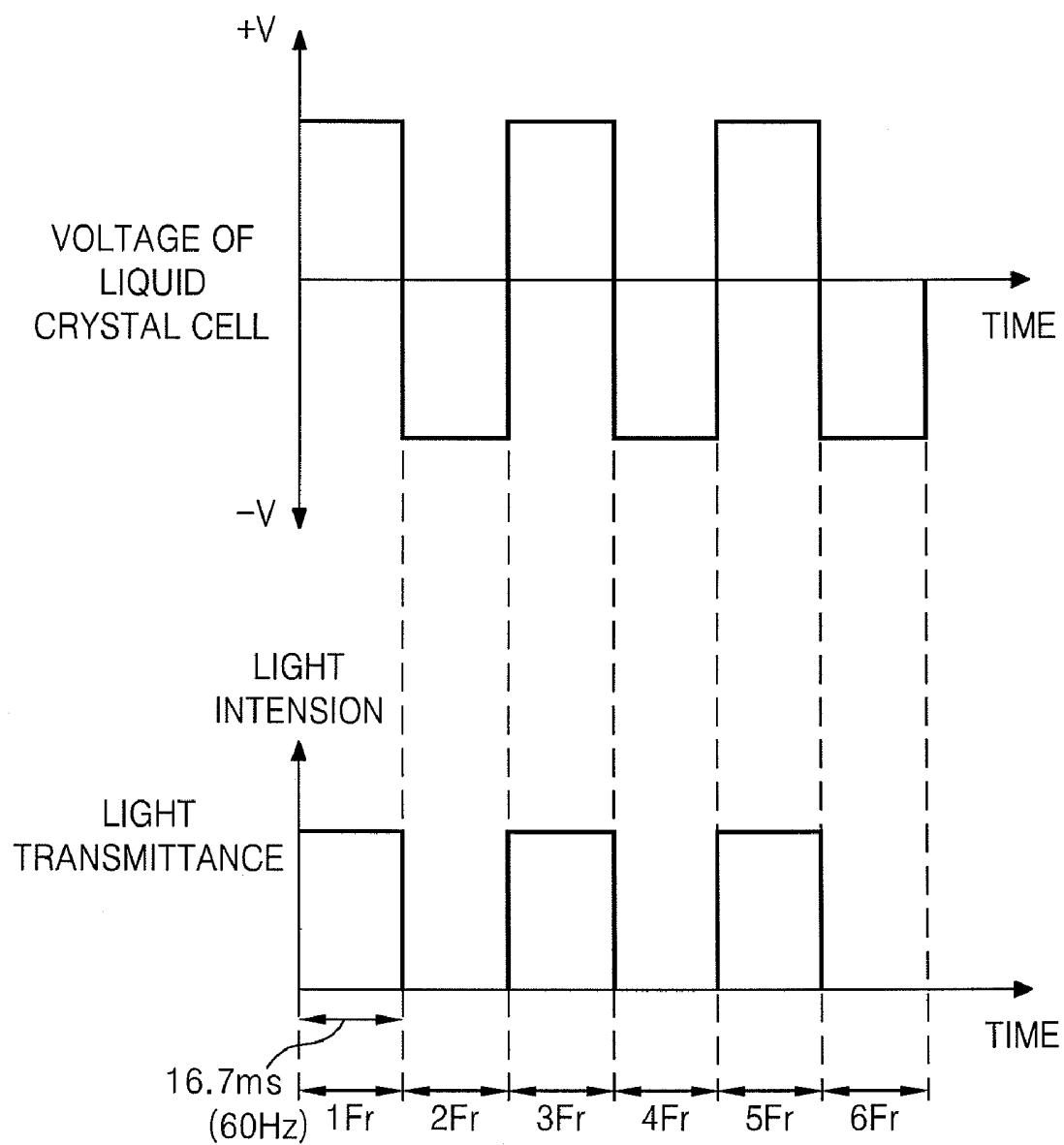


FIG. 18B

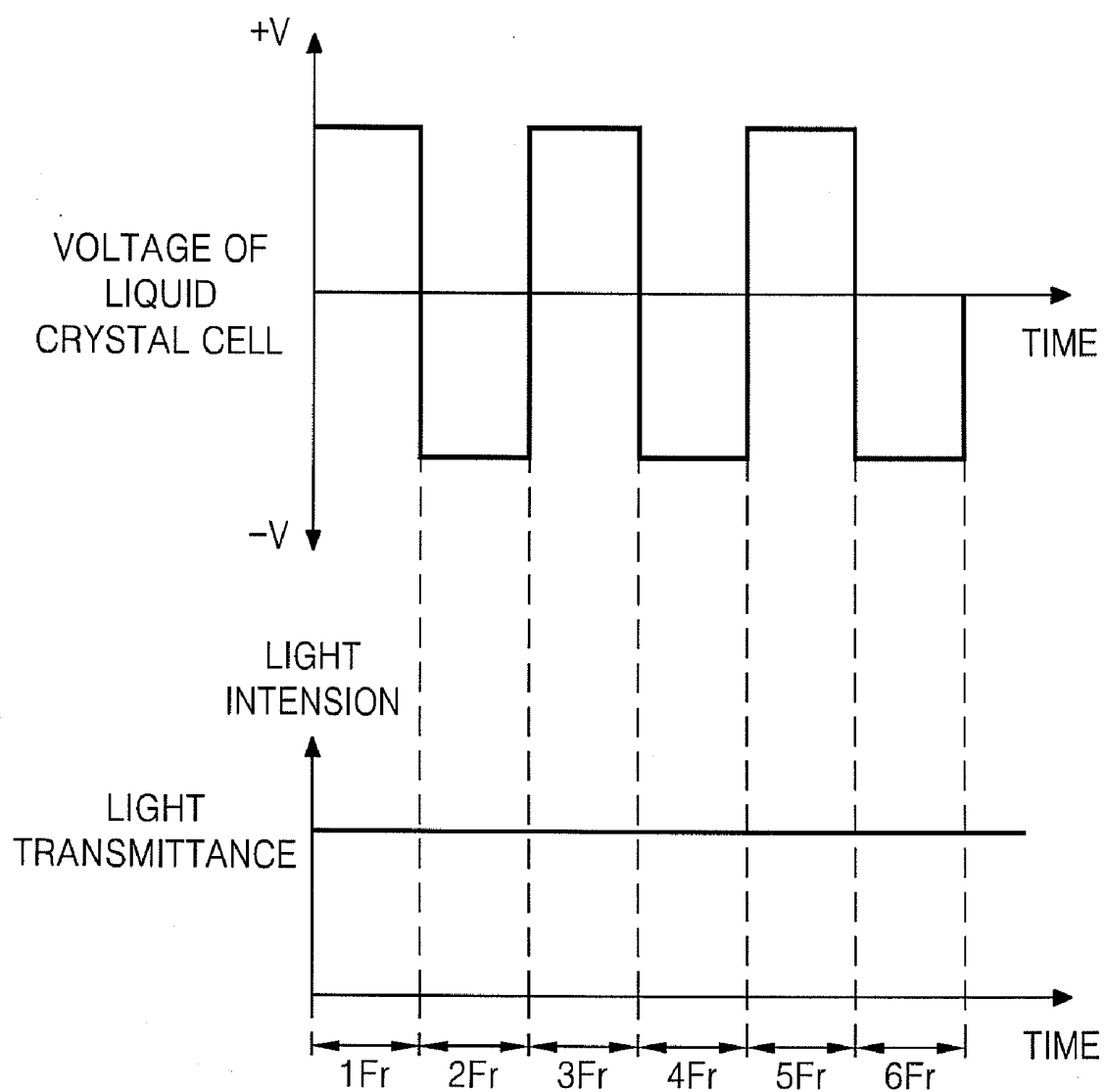


FIG. 19A

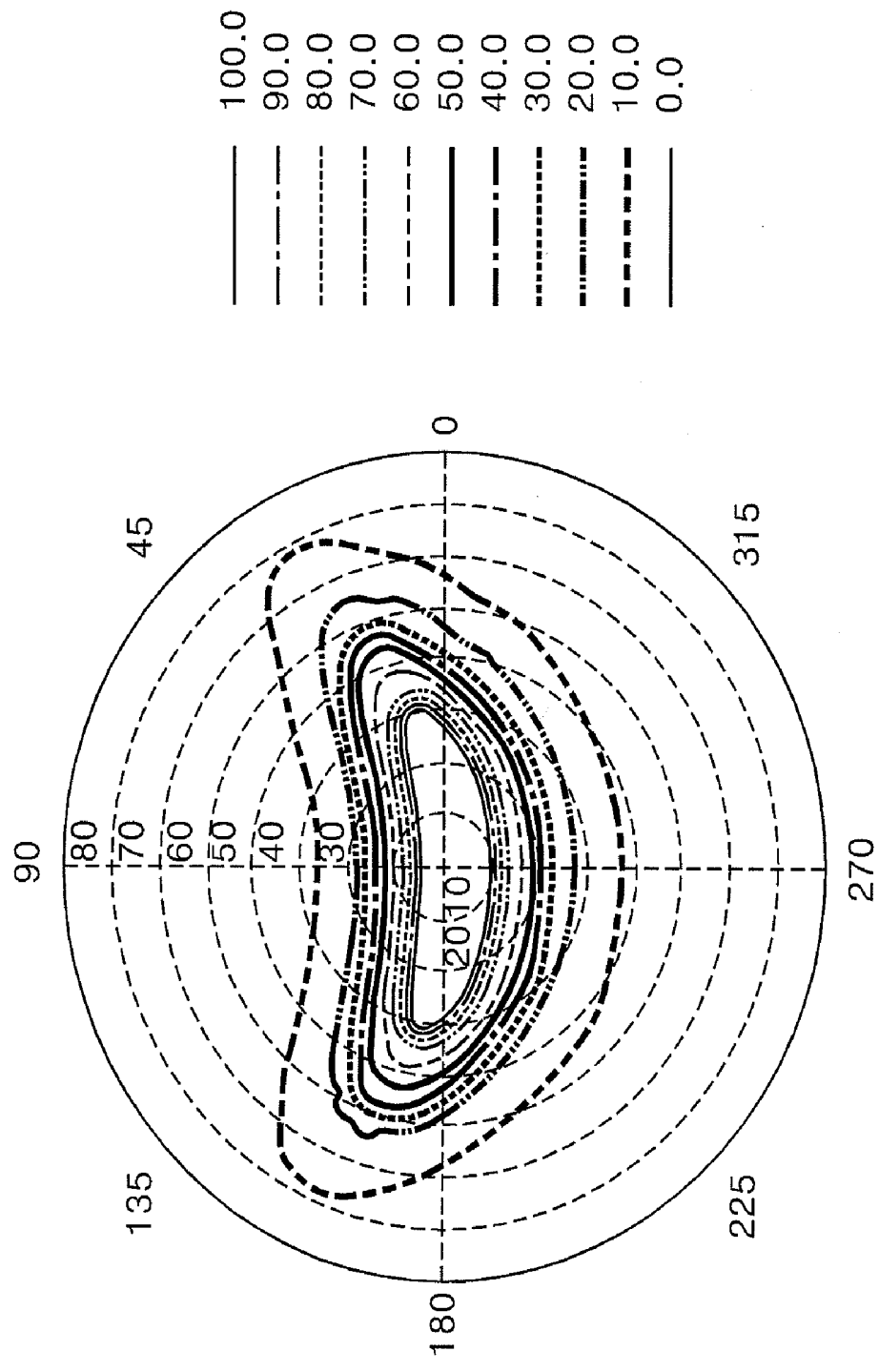


FIG. 19B

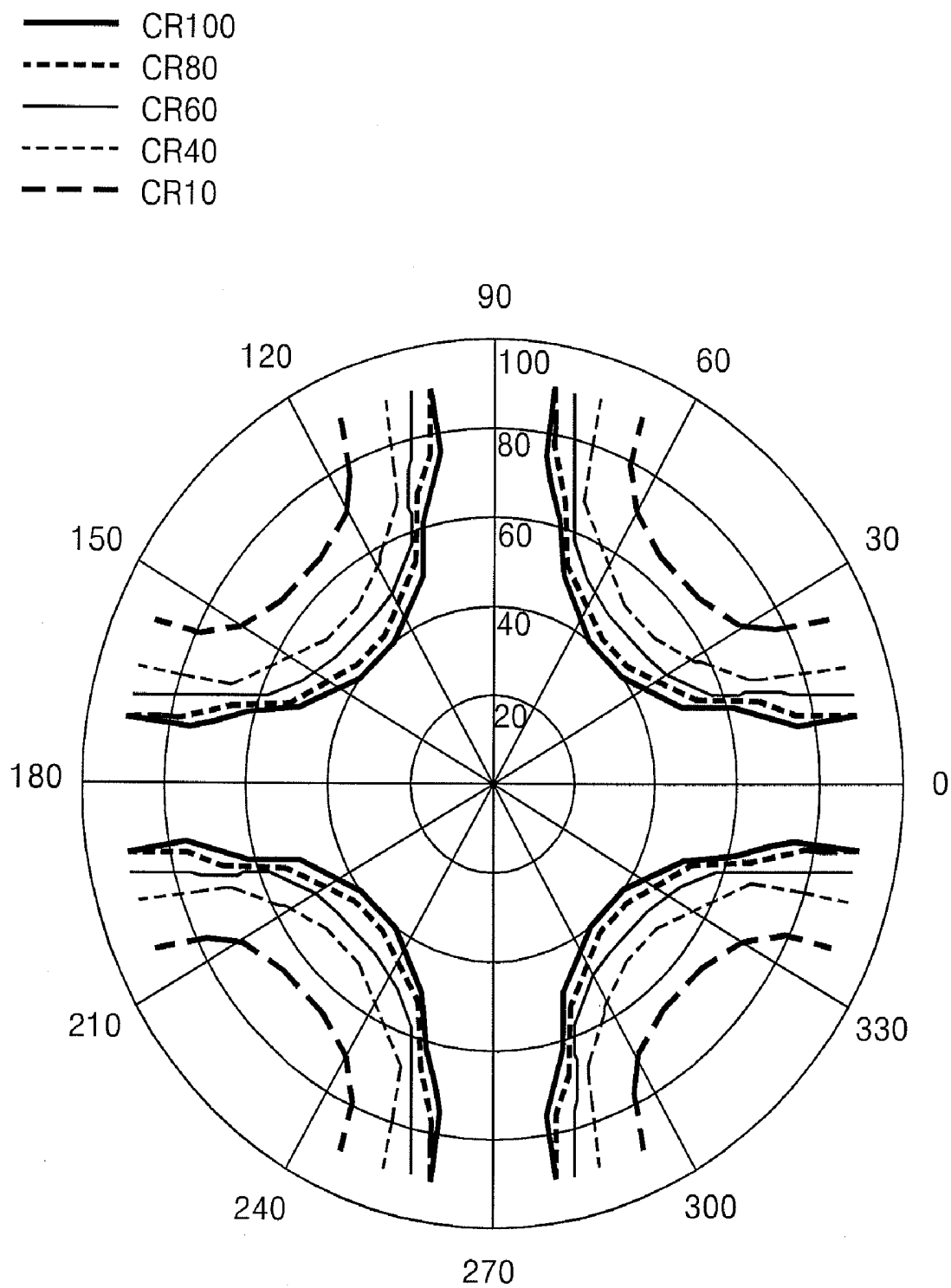


FIG.20A

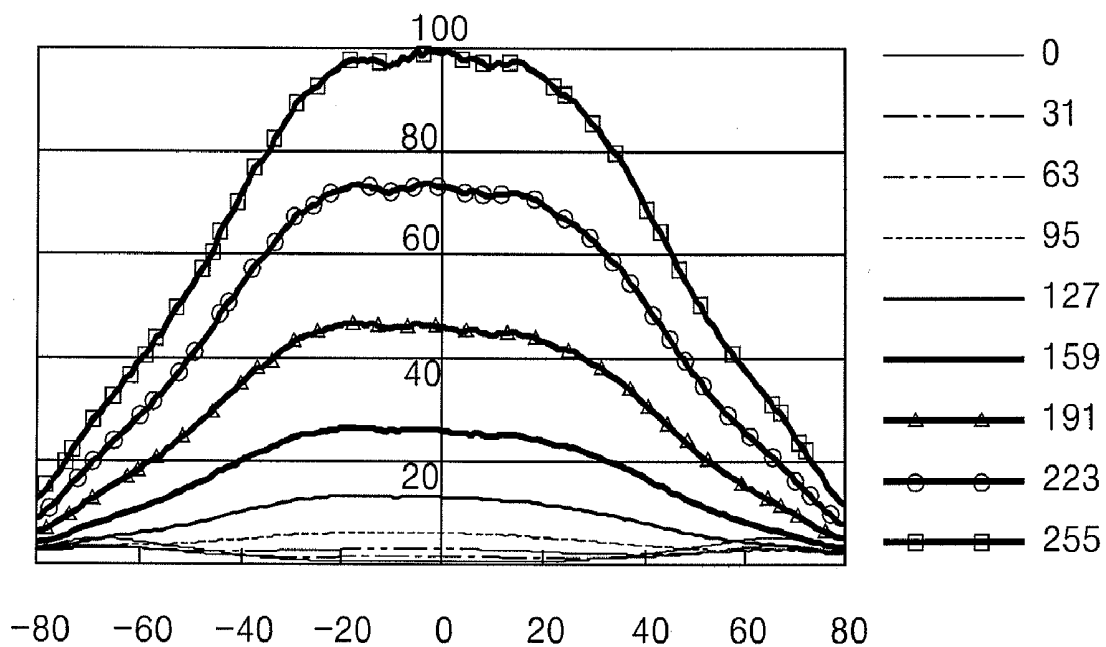


FIG. 20B

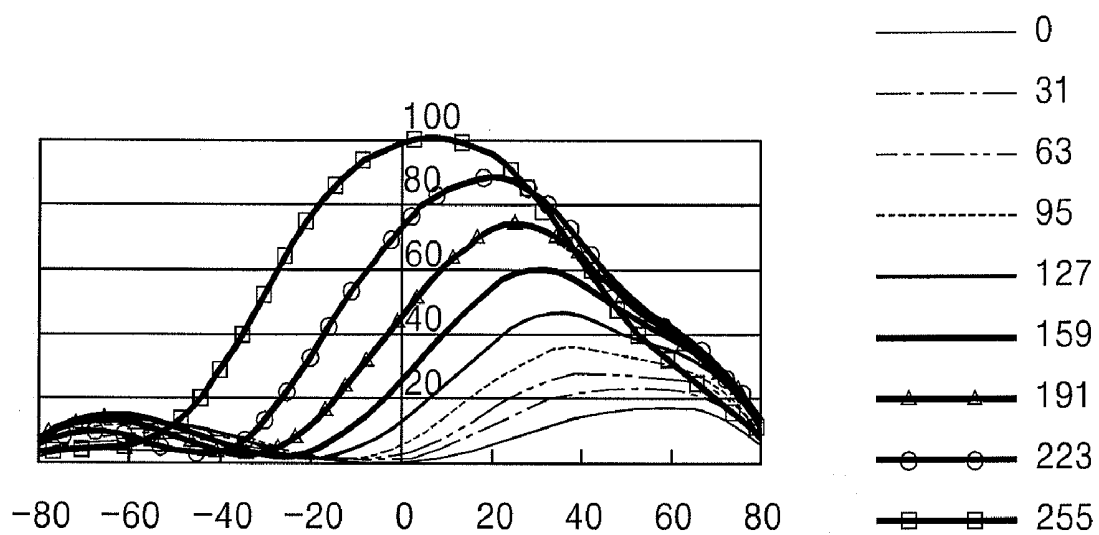
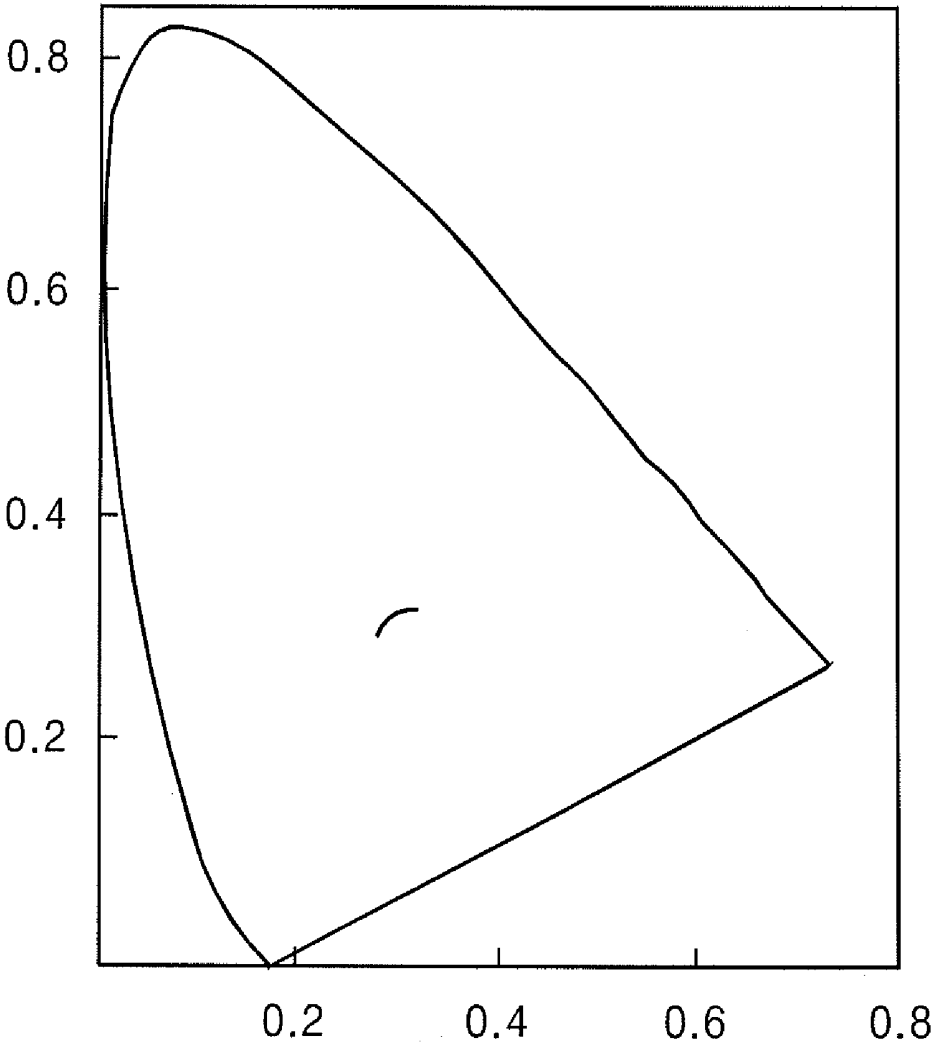


FIG.21



# LIQUID CRYSTAL DISPLAY DEVICE OF IN-PLANE SWITCHING MODE, METHOD OF FABRICATING THE SAME, AND METHOD OF DRIVING THE SAME

## PRIORITY CLAIM

[0001] This application claims priority to patent application Ser. No. 11/091,199, which claims the benefit of Korean Patent Application No. P2004-21127 filed in Korea on Mar. 29, 2004, and Korean Patent Application No. P2004-21985 filed in Korea on Mar. 31, 2004, which are hereby incorporated by reference.

## TECHNICAL FIELD

[0002] The present application relates to a liquid crystal display device of in-plane switching mode, a method of fabricating the same, and a method of driving the same, and more particularly, to a liquid crystal display device of in-plane switching mode, a method of fabricating the same, and a method of driving the same that is possible to improve an aperture ratio and to reduce a light leakage without a compensation film.

## DESCRIPTION OF THE RELATED ART

[0003] A related art liquid crystal display (LCD) device controls an electric field applied to a liquid crystal cell and modulates light incident to the liquid crystal cell to thereby display a picture. A liquid crystal material injected into the liquid crystal display device is in between a solid and a liquid, having both fluidity and elasticity.

[0004] Presently, most frequently used the liquid crystal mode of the liquid crystal display device is a twisted nematic (TN) mode, driven by a vertical electric field scheme. The TN mode has a relatively high aperture ratio. However, implementation of a wide viewing angle is difficult because the refractive index of the liquid crystal material, which an observer senses in accordance with the viewing angle, is substantially difficult. In addition, the response speed of the liquid crystal material is slow.

[0005] An in-plane switching (IPS) mode is representative of a horizontal electric field scheme. In the IPS mode, an electric field is formed between electrodes formed on a substrate, and liquid crystal molecules are driven by the electric field.

[0006] FIG. 1 is a sectional view illustrating a related art liquid crystal panel of in-plane switching mode.

[0007] Referring to FIG. 1, the related art in-plane switching mode liquid crystal display panel includes upper and lower substrates 12 and 18, which are combined by a sealant (not shown), and upper and lower polarizing plates 11 and 19, which are respectively located at a rear surface of the upper and lower substrates 12 and 18.

[0008] On the upper substrate 12, a color filter and a black matrix, etc., are formed. On the lower substrate, a pixel electrode 16 is formed in parallel to a common electrode 15, and an electric field 20 of the horizontal direction is formed by a difference of voltages applied in between the electrodes 15 and 16. Liquid crystal molecules 14 are rotated within a surface direction of the substrate by the electric field 20 to modulate a polarization component of light transmitting a liquid crystal layer.

[0009] As shown in FIGS. 2A and 2B, light transmitting axes of the upper/lower polarizing plates 11 and 19 are

crossed vertically each other. In other words, if the light transmitted through the liquid crystal layer is changed into linearly polarized light, then the light passes through the upper polarizing plate 11 to progress toward an observer. On the other hand, if the polarization component of the light does not change when the light passes through the liquid crystal layer, then the light does not pass through the upper polarizing plate 11.

[0010] The upper polarizing plate 11 has a structure which first and second protective layers 11a and 11c are stacked with a polarizer 11b therebetween. The lower polarizing plate 19 has a structure which first and second protective layers 19a and 19c are stacked with a polarizer 19b therebetween.

[0011] The polarizers 11b and 19b are formed by stretching a poly vinyl alcohol film and soaking it in an iodine and a dichroic dye solution to arrange iodine molecules, in parallel, in a stretching direction.

[0012] The first and the second protective layers 11a, 11c, 19a and 19c are made of tri-acetyl cellulose TAC, etc. The first and the second protective layers 11a, 11c, 19a and 19c serve to prevent the oriented polarizers 11b and 19b from being shrunk and to protect the polarizers 11b and 19b.

[0013] When the liquid crystal panel shown in FIG. 1 implements black, light that has been linearly polarized by the lower polarizing plate 19 is not absorbed sufficiently by the upper polarizing plate 11, so that the amount and color of the light seen from a location out of a front surface of the liquid crystal display device, i.e., from a lateral surface may be differentiated as compared with the amount and color of light seen from the front surface of the liquid crystal display device. More particularly, as shown in FIGS. 3 and 4, when a viewing angle is  $\pm 70^\circ$ , light transmittance is high. Accordingly, most of the light leakage occurs in these regions. This is because the first and the second protective layers 11a and 11c of the upper polarizing plate 11 are uni-axial and have a regular delay value to change a polarizing direction of the upper polarizing plate 11.

[0014] In order to reduce light leakage, as shown in FIG. 5, compensation films 7 and 9 such as A-plate, positive C-plate, biaxial film and the like are attached to the rear surface of each of the upper and lower substrates 12 and 18 together with the polarizing plate. Light leakage can be reduced by use of the compensation films 7 and 9, as shown in FIGS. 3 and 6.

[0015] However, the liquid crystal panel shown in FIG. 5 has a problem that cost increases due to the additional compensation films 7 and 9. Further, the stretching intensity is not applied uniformly over the entire area of the compensation films 7 and 9 upon stretching of the compensation films 7 and 9 applied for a large-dimension substrate.

[0016] Moreover, in the related art IPS mode liquid crystal display, since the electric field applied to the liquid crystal molecules 14 is bent on the pixel electrode 16 and the common electrode 15, switching of the light is not normally performed on the electrodes 15 and 16. As a result, the IPS mode liquid crystal display has a low aperture ratio.

## SUMMARY

[0017] An in-plane switching mode liquid crystal display device, a method of fabricating the same, and a method of driving the same are provided with improved aperture ratio and reduced light leakage without a compensation film.

[0018] In one embodiment, the in-plane switching mode liquid crystal display device includes opposing substrates, opposing electrodes formed on the substrates, and a multi-

layer liquid crystal layer disposed between the electrodes. The multilayer liquid crystal layer contains opposing layers having a first type of liquid crystal molecules and a middle layer therebetween having a second type of liquid crystal molecules.

[0019] In another embodiment, a method of driving the liquid crystal display device includes applying an electric field to the opposing layers using the opposing electrodes and in-plane driving liquid crystal molecules in the middle layer by permitting one of the opposing layers to react to the electric field.

[0020] In another embodiment, a method of fabricating an in-plane switching mode liquid crystal display device includes forming an electrode and a first liquid crystal layer on each of an upper and lower substrate, exposing each first liquid crystal layer to an amphiphilic or amphiphobic medium, stabilizing each of the exposed first liquid crystal layers in a mono-stable state and providing a second liquid crystal layer between the stabilized first liquid crystal layers.

[0021] In any of the above embodiments, one or more of the following may be true: the opposing layers comprise ferroelectric liquid crystal molecules, the ferroelectric liquid crystal molecules comprise chiral smectic C phase liquid crystal molecules, the middle layer comprises nematic liquid crystal molecules, the opposing layers have different spontaneous polarization directions, liquid crystal molecules in the opposing layers react to electric fields formed by the opposing electrodes to produce in-plane driving of liquid crystal molecules in the middle layer, a phase difference value of each of the opposing layers is 10 nm to 150 nm, opposing alignment films are formed on the substrates, each of the opposing alignment films includes an amphiphilic medium or an amphiphobic medium, spontaneous polarization of each opposing layer is directed toward the alignment film most proximate or most distal to the opposing layer, only one of the opposing layers reacts to an applied electric field, the opposing layers react to electric fields of different polarities, the opposing layers are driven under half V-switching mode, a phase transition of each first liquid crystal layer causes the stabilization, each first liquid crystal layer undergoes multiple phase transitions before the second crystal layer is provided between the first liquid crystal layers, the stabilization occurs without an external electric field being applied to either of the first liquid crystal layers, a mixture of liquid crystal material and an organic solvent is applied to each substrate and the substrate is heated to a temperature sufficient to vaporize the organic solvent, and/or the liquid crystal material is cooled after the organic solvent is vaporized to produce a phase transition in the liquid crystal material (from an isotropic phase to a chiral smectic C phase possibly with a chiral nematic phase therebetween).

#### BRIEF DESCRIPTION OF THE DRAWINGS

[0022] The following detailed description of the embodiments of the present invention reference the accompanying drawings, in which:

[0023] FIG. 1 is a schematically sectional view illustrating a related art liquid crystal panel of in-plane switching mode;

[0024] FIGS. 2A and 2B are plan views illustrating upper/lower polarizing plates shown in FIG. 1;

[0025] FIG. 3 is a graph showing a viewing angle property before using a related art compensation film, and after using the related art compensation film;

[0026] FIG. 4 is a configuration showing a viewing angle property of the liquid crystal display panel shown in FIG. 1;

[0027] FIG. 5 is a sectional view illustrating the related art liquid crystal display panel having a compensation film;

[0028] FIG. 6 is a configuration showing a viewing angle property of the liquid crystal display panel shown in FIG. 5;

[0029] FIG. 7 is a block diagram showing an in-plane switching mode liquid crystal display device according to one embodiment of the present invention;

[0030] FIG. 8 is a sectional view illustrating the in-plane switching mode liquid crystal display panel shown in FIG. 7;

[0031] FIG. 9 is a sectional view illustrating another type liquid crystal display panel different from the in-plane switching mode liquid crystal display panel shown in FIG. 8;

[0032] FIG. 10 is a configuration for explaining the phase difference value of a ferroelectric liquid crystal layer shown in FIGS. 7 and 8;

[0033] FIGS. 11A to 11D are sectional views sequentially illustrating a method of fabricating the in-plane switching mode liquid crystal display panel shown in FIG. 9;

[0034] FIG. 12 is a configuration showing a ferroelectric liquid crystal material stabilized in a mono-stable state during a phase transition process of FIGS. 11A to 11D;

[0035] FIGS. 13A to 13D are sectional views sequentially illustrating a method of fabricating the in-plane switching mode liquid crystal display panel shown in FIG. 8;

[0036] FIG. 14 is a configuration showing a ferroelectric liquid crystal material stabilized in a mono-stable state during a phase transition process of FIGS. 13A to 13D;

[0037] FIGS. 15A and 15B are detailed configurations showing a movement of in-plane switching mode of the ferroelectric liquid crystal material and the nematic system liquid crystal material shown in FIG. 9;

[0038] FIG. 16 is a configuration showing a liquid crystal panel, to which a ferroelectric liquid crystal layer of half V-switching mode is injected, driven by a dot inversion system;

[0039] FIG. 17 is a configuration showing a liquid crystal panel, in which a nematic system liquid crystal layer is put in between the ferroelectric liquid crystal layers of half V-switching mode as shown in FIG. 8 or FIG. 9, driven by a dot inversion system;

[0040] FIGS. 18A and 18B are graphs showing light transmittance of the liquid crystal panels shown in FIGS. 16 and 17, wherein the liquid crystal panels are driven by the dot inversion system, respectively;

[0041] FIGS. 19A and 19B are configurations showing a viewing angle of a general twisted nematic mode liquid crystal display panel and the in-plane switching mode liquid crystal display panel according to one embodiment of the present invention, respectively;

[0042] FIGS. 20A and 20B are graphs showing gray level inversion of the general twisted nematic mode liquid crystal display panel; and

[0043] FIG. 21 is a graph showing color coordinates in the in-plane switching mode liquid crystal display device according to one embodiment of the present invention.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0044] Reference will now be made in detail to the preferred embodiments of the present invention, examples of which are illustrated in the accompanying drawings.

[0045] Hereinafter, the preferred embodiments of the present invention will be described in detail with reference to FIGS. 7 to 21.

[0046] FIG. 7 is a block diagram showing an in-plane switching mode liquid crystal display device according to one embodiment of the present invention.

[0047] Referring to FIG. 7, the in-plane switching mode liquid crystal display device according to one embodiment of the present invention includes: a liquid crystal display panel 64 in which a nematic liquid crystal material is disposed between ferroelectric liquid crystal layers; a data driver 62 for driving a data line D of the liquid crystal display panel 64; a gate driver 63 for driving a gate line G of the liquid crystal display panel 64; a timing controller 61 for controlling the data driver 62 and the gate driver 63; and a common voltage generator 65 for applying a common voltage Vcom to a common electrode of the liquid crystal display panel 64.

[0048] The timing controller 61 supplies a pixel data signal R,G,B data applied from an exterior to the data driver 62. Further, the timing controller 61 generates a gate control signal GDC and a data control signal DDC in response to control signals H (horizontal period), V (vertical period), DE, and CLK (system clock) supplied from the exterior. Herein, the gate control signal GDC is for controlling the gate driver 63 and the data control signal DDC is for controlling the data driver 62.

[0049] The gate control signal GDC includes a gate start pulse GSP, a gate shift clock pulse GSC, a gate output enable signal GOE, and etc. The data control signal DDC includes a source start pulse SSP, a source shift clock signal SSC, a source output enable signal SOE, a polarity control signal POL, and etc.

[0050] The gate driver 63 sequentially applies a high gate voltage VGH to the gate lines GL1 to GLm in response to the gate control signal GDC from the timing controller 61. Accordingly, the gate driver 63 allows a thin film transistor TFT connected to the gate lines G1 to Gm to be driven by a gate line GL unit.

[0051] The data driver 62 applies pixel signals for each one horizontal line to the data lines DL1 to DLn every horizontal period (H1, H2, ...) in response to the data signal DDC from the timing controller 61. More particularly, the data driver 62 converts digital pixel data R, G, and B from the timing controller 61 into analog pixel signals using a gamma voltage from a gamma voltage generator (not shown) to output them.

[0052] As shown in FIG. 8 or FIG. 9, the liquid crystal display panel 64 includes: an upper plate 100 and a lower plate 110, which are combined by a sealant (not shown); first and second ferroelectric liquid crystal layers 24 and 34 formed on the upper plate 100 and the lower substrate 110, respectively; and a nematic liquid crystal material 50 between the first and the second ferroelectric liquid crystal layers 24 and 34.

[0053] The upper plate 100 includes: an upper substrate 21; a color filter (not shown) for representing a color; a black matrix (not shown) for preventing light leakage; a common electrode 22 to which the common voltage Vcom generated from the common voltage generator 65 is applied; and an upper alignment film 23 applied to the common electrode 22 that aligns the first layer of ferroelectric liquid crystal molecules 24.

[0054] The lower substrate 110 includes: data lines (D1-Dn) to which data signals are supplied; gate lines (G1-Gm) to which gate signals are supplied; a thin film transistor (TFT)

for switching liquid crystal cells at a crossing of the data lines and the gate lines; a pixel electrode 32 connected to the thin film transistor TFT to drive the liquid crystal cells; and a lower alignment film 33 applied to the pixel electrode 32 that aligns the second layer of ferroelectric liquid crystal molecules 34.

[0055] Polarizers (not shown) whose light transmitting axes are vertically crossed with each other are attached on a light incident surface of the lower substrate 110 and on a light exit surface of the upper substrate 100, respectively.

[0056] The first and the second ferroelectric liquid crystal layers 24 and 34 are driven in a half V-switching mode and their spontaneous polarization directions are different from each other.

[0057] For instance, as shown in FIG. 8, when the first ferroelectric liquid crystal layer 24 has the same spontaneous polarization direction as a negative polarity electric field direction, the second ferroelectric liquid crystal layer 34 has the same spontaneous polarization direction as a positive polarity electric field direction. At this time, the first ferroelectric liquid crystal layer 24 reacts to the positive polarity electric field, so that as the spontaneous polarization direction of the first ferroelectric liquid crystal material 24 is changed to the same direction as the positive polarity electric field direction, the first ferroelectric liquid crystal layer 24 is driven under in-plane switching. On the other hand, the second ferroelectric liquid crystal layer 34 reacts to the negative polarity electric field, so that as the spontaneous polarization direction of the second ferroelectric liquid crystal material 34 is changed to the same direction as the negative polarity electric field direction, the second ferroelectric liquid crystal layer 34 is driven under in-plane switching.

[0058] Otherwise, as shown in FIG. 9, when the first ferroelectric liquid crystal layer 24 has the same spontaneous polarization direction as the positive polarity electric field direction, the second ferroelectric liquid crystal layer 34 has the same spontaneous polarization direction as the negative polarity electric field direction. At this time, the first ferroelectric liquid crystal layer 24 reacts to the negative polarity electric field, so that as the spontaneous polarization direction of the first ferroelectric liquid crystal material 24 is changed to the same direction as the negative polarity electric field direction, the first ferroelectric liquid crystal layer 24 is driven under in-plane switching. On the other hand, the second ferroelectric liquid crystal layer 34 reacts to the positive polarity electric field, so that as the spontaneous polarization direction of the second ferroelectric liquid crystal material 34 is changed to the same direction as the positive polarity electric field direction, the second ferroelectric liquid crystal layer 34 is driven under in-plane switching.

[0059] Meanwhile, as shown in FIG. 10, the first and the second ferroelectric liquid crystal layers 24 and 34 are formed to have a phase difference value identical to that of the related art compensation film. For instance, a phase difference value  $\Delta n$  of each of the first and the second ferroelectric liquid crystal layers 24 and 34 is about 10 nm to 150 nm. Herein,  $\Delta n$  represents a refractive index anisotropy of each of the first and the second ferroelectric liquid crystal molecules, and d represents a thickness of each of the first and the second ferroelectric liquid crystal layers 24 and 34.

[0060] The nematic liquid crystal layer 50 has a switching angle of 90° and forms an interface with the first and the second ferroelectric liquid crystal layers 24 and 34. The nematic liquid crystal layer 50 is driven under in plane switching

by the first or the second ferroelectric liquid crystal layers **24** and **34** as the spontaneous polarization direction of the nematic liquid crystal layer **50** is changed to the same direction as the electric field direction.

**[0061]** FIGS. **11A** to **11D** are sectional views sequentially illustrating a method of fabricating the in-plane switching mode liquid crystal display panel. Herein, the upper plate and the lower plate in FIG. **8** are manufactured by the method as in FIGS. **11A** to **11D**.

**[0062]** An electrode **52** and an amphiphilic alignment film **53** are formed on a substrate **51** as shown in FIG. **11A**. The electrode **52** is made of a transparent conductive material such as an indium-tin-oxide (ITO). Since the amphiphilic alignment film **53** has electric negativity such as a polyamic acid, the amphiphilic alignment film **53** electrically represents a polarity and is made of an organic alignment material capable of aligning a liquid crystal material. The amphiphilic alignment film **53** is rubbed in order to settle an alignment direction of ferroelectric liquid crystal molecules.

**[0063]** Subsequently, a mixture in which the ferroelectric liquid crystal material and an organic solvent are uniformly mixed is applied to the substrate **51** such that the substrate **51** is exposed to an amphiphobic medium almost not representing electric polarity, and then the substrate **51** temperature is increased to between 140° C. to 160° C. to vaporize the organic solvent. As a result, a ferroelectric liquid crystal layer **54** of an isotropic phase is formed on the substrate **51**. Herein, the amphiphobic medium may be selected from an atmosphere of air or nitrogen N<sub>2</sub>, for example.

**[0064]** Next, the temperature of the substrate **51** is lowered to between 110° C. to 85° C. to permit a phase transition of the ferroelectric liquid crystal layer **54** from the isotropic phase to a chiral nematic phase (N\*) as shown in FIG. **11C**. Further, in order to permit a phase transition between the ferroelectric liquid crystal layer **54** from the chiral nematic phase (N\*) to a chiral smectic C phase (Sm C\*) as shown in FIG. **11D**, the temperature of the glass substrate **51** is further lowered to between 80° C. to 50° C. At this time, as shown in FIG. **12**, a spontaneous polarization Ps is generated in the liquid crystal molecules of the ferroelectric liquid crystal layer **54** during the phase transition to the chiral smectic C phase (Sm C\*), and the direction of the spontaneous polarization Ps is directed to the amphiphilic alignment film **53**. In other words, while the liquid crystal molecules of the ferroelectric liquid crystal layer **54** are subject to the phase transition to the chiral smectic C phase (Sm C\*), the direction of the spontaneous polarization Ps is uniformly arranged to a mono-stable state without an external electric field being applied.

**[0065]** FIGS. **13A** to **13D** are sectional views sequentially illustrating a method of fabricating an in-plane switching mode liquid crystal display panel according to another embodiment of the present invention. Herein, the upper plate and the lower plate in FIG. **9** are manufactured by the method as in FIGS. **13A** to **13D**.

**[0066]** An electrode **52** and an alignment film **53** are formed on a substrate **51** as shown in FIG. **13A**. The electrode **52** is made of a transparent conductive material such as an indium-tin-oxide (ITO). The alignment film **53** is made of an organic alignment material such as a polyamic acid, and the alignment film **53** is rubbed in order to settle an alignment direction of ferroelectric liquid crystal molecules.

**[0067]** Subsequently, a mixture in which the ferroelectric liquid crystal material and an organic solvent are uniformly mixed is applied to the substrate **51**, which is exposed under

an amphiphobic medium, e.g., under an atmosphere of H<sub>2</sub>O or O<sub>2</sub>, having a high electric negativity (i.e., a high polarity) compared to the alignment film **53** as shown in FIG. **13B**, and a temperature of the substrate **51** is increased to between 140° C. to 160° C. to vaporize the organic solvent. As a result, a ferroelectric liquid crystal layer **54** of an isotropic phase is formed on the substrate **51**.

**[0068]** In order to produce a phase transition in the ferroelectric liquid crystal layer **54** from the isotropic phase to the chiral nematic phase (N\*) as shown in FIG. **13C**, the temperature of the substrate **51** is lowered to between 110° C. to 85° C. Further, in order to produce a phase transition in the ferroelectric liquid crystal layer **54** from the chiral nematic phase (N\*) as shown in FIG. **13C** to the chiral smectic C phase (Sm C\*) as shown in FIG. **13D**, the temperature of the substrate **51** is further lowered to between 80° C. to 50° C. At this time, as shown in FIG. **14**, a spontaneous polarization Ps is generated in the liquid crystal molecules of the ferroelectric liquid crystal layer **54** during the phase transition process transitioned to the chiral smectic C phase (Sm C\*), and the direction of the spontaneous polarization Ps is directed toward the amphiphilic medium on the opposite side to the alignment film **53**. This is because the amphiphilic medium on opposite the alignment film **53** has a higher electrical negativity than the alignment film **53**. In other words, while the liquid crystal molecules of the ferroelectric liquid crystal layer **54** are subject to the phase transition to the chiral smectic C phase (Sm C\*), the direction of the spontaneous polarization Ps is uniformly arranged to a mono-stable state without an external electric field being applied.

**[0069]** FIGS. **15A** and **15B** are sectional views illustrating a method of driving the liquid crystal display device according to one embodiment of the present invention. For instance, FIGS. **15A** and **15B** represent a change of the ferroelectric liquid crystal molecules arrangement of the half V-switching mode when respective external electric fields (E(+)) and (E(-)) of a positive polarity and a negative polarity are applied to the half V-switching mode ferroelectric liquid crystal molecule arrangement aligned in a direction corresponding to the negative polarity electric field (E(-)).

**[0070]** As shown in FIG. **15A**, when a positive polarity electric field is applied to the liquid crystal display panel having the first and the second ferroelectric liquid crystal materials **24** and **34** and the nematic liquid crystal material, the spontaneous polarization direction of the first ferroelectric liquid crystal material **24** is changed to the same direction as the positive polarity electric field direction. The first ferroelectric liquid crystal material **24** is then driven in the in-plane direction and the nematic liquid crystal material adjacent to the first ferroelectric liquid crystal material **24** is driven under the in-plane switching. The second ferroelectric liquid crystal material **34** having the same spontaneous polarization direction as the positive polarity electric field direction does not react to the electric field and maintains an incipient arrangement state. At this time, as the nematic liquid crystal material **50** is switched in plane only by the first ferroelectric liquid crystal material **24**, the nematic liquid crystal **50** becomes twisted in a vertical direction.

**[0071]** Furthermore, as shown in FIG. **15B**, when a negative polarity electric field is applied to the liquid crystal display panel having the first and the second ferroelectric liquid crystal materials **24** and **34** and the nematic liquid crystal material, the spontaneous polarization direction of the second ferroelectric liquid crystal material **34** is changed to the same

direction as the negative polarity electric field direction. The second ferroelectric liquid crystal material **34** is then driven in the in-plane direction and the nematic liquid crystal material adjacent to the second ferroelectric liquid crystal material **50** is driven under in plane switching. Further, the first ferroelectric liquid crystal material **24** having the same spontaneous polarization direction as the negative polarity electric field direction does not react to the electric field and maintains an incipient arrangement state. At this time, as the nematic liquid crystal material **50** is switched in plane only by the second ferroelectric liquid crystal material **34**, the nematic liquid crystal **50** becomes twisted in a vertical direction.

**[0072]** The in-plane switching mode liquid crystal display device assures implementation of a wide viewing angle by virtue of in-plane driving of the nematic liquid crystal **50** as well as minimizing deterioration of the aperture ratio by applying an electric field to the liquid crystal **50** under a vertical electric field scheme. Further, since the nematic liquid crystal **50** is rapidly moved by the ferroelectric liquid crystal materials **24** and **34**, it is possible to improve the response speed of the nematic liquid crystal **50**.

**[0073]** FIG. **16** is a configuration showing a liquid crystal panel to which a half V-switching mode ferroelectric liquid crystal layer is driven by dot inversion, and FIG. **17** is a configuration showing a liquid crystal panel, in which a nematic liquid crystal layer between the half V-switching mode ferroelectric liquid crystal layers as shown in FIG. **8** or FIG. **9**, is driven by dot inversion.

**[0074]** As shown in FIG. **16**, if a liquid crystal display device having a half V-switching mode ferroelectric liquid crystal cell aligned by a negative polarity electric field is driven by dot inversion, then the ferroelectric liquid crystal cells transmit light alternately one by one because the ferroelectric liquid crystal cell transmits light only in the positive polarity electric field. In other words, the odd liquid crystal cells of an odd horizontal line and the even ferroelectric liquid crystal cells of an even horizontal line transmit light in response to the positive polarity electric field (+) in an odd frame and intercept light in response to the negative polarity electric field (−) in an even frame. Even liquid crystal cells of an odd horizontal line and odd ferroelectric liquid crystal cells of an even horizontal line intercept light in response to the negative polarity electric field (−) in an odd frame and transmit light in response to the positive polarity electric field (+) in an even frame. At this time, as shown in FIG. **18A**, 60 Hz data, i.e., the electric field of which polarity is inverted at each frame period, is applied to a free liquid crystal cell. The liquid crystal cell transmits light only in an odd frame period (1 Fr, 3 Fr, 5 Fr) to which the positive polarity electric field is applied. Accordingly, if the half V-switching mode ferroelectric liquid crystal cell is uniformly aligned under electric field through the whole panel and is driven in an inversion system, then because a visitor perceives light periodically at each frame period, the brightness of display picture is lowered and the display picture flickers.

**[0075]** On the other hand, as shown in FIG. **17**, if the half V-switching mode liquid crystal display panel in which the nematic liquid crystal layer is between the first and the second ferroelectric liquid crystal layers is driven by dot inversion, then one of the first or the second ferroelectric liquid crystal layers is in-plane switched in the positive polarity electric field and the another is in-plane switched in the negative polarity electric field. For instance, the first ferroelectric liquid crystal layer is in-plane switched in the positive polarity

electric field and the second ferroelectric liquid crystal layer is in-plane switched in the negative polarity electric field.

**[0076]** In other words, the odd liquid crystal cells of an odd horizontal line and the even ferroelectric liquid crystal cells of an even horizontal line transmit light in response to the positive polarity electric field (+) in an odd frame and transmit light in response to the negative polarity electric field (−) in an even frame. Even liquid crystal cells of an odd horizontal line and odd ferroelectric liquid crystal cells of an even horizontal line transmit light in response to the negative polarity electric field (−) in an odd frame and transmit light in response to the positive polarity electric field (+) in an even frame. At this time, as shown in FIG. **18B**, 60 Hz data, i.e., the electric field of which polarity is inverted in each frame period, is applied to a free liquid crystal cell. The liquid crystal cell transmits light in an odd frame period (1 Fr, 3 Fr, 5 Fr) to which the positive polarity electric field is applied and transmits light in an even frame period (2 Fr, 4 Fr, 6 Fr) to which the negative polarity electric field is applied. Accordingly, even though the half V-switching mode ferroelectric liquid crystal cell is uniformly aligned under electric field through the whole panel and is driven in an inversion system, because a visitor perceives light periodically every frame period, the brightness of display picture is improved.

**[0077]** FIGS. **19A** and **19B** are configurations showing a viewing angle of a twisted nematic mode general liquid crystal display panel and the in-plane switching mode liquid crystal display panel according to the present invention, respectively. In FIGS. **19A** and **19B**, azimuth angles 90°, 270°, 180° and 0°, respectively, represent upper/lower/left/right viewing angles. Concentric circles represent inclination angles, which is inclined from a display surface to the declination angle.

**[0078]** As shown in FIG. **19A**, the general twisted nematic mode liquid crystal display device can obtain contrast ratio of 100 at an inclination angle 10° for azimuth angles 45°, 135°, 225°, and 315°, and can obtain contrast ratio of 0 to 10 at inclination angles more than 50°. In other words, in the general twisted nematic mode liquid crystal display device, the range of viewing angles capable of obtaining a high contrast ratio is relatively narrow.

**[0079]** Further, in the general twisted nematic mode liquid crystal display device brightness in accordance with the viewing angle of upper/lower/left/right directions should be increased by an applied voltage. However, gray level inversion occurs, decreasing the brightness even through the applied voltage is increased. For instance, as shown in FIG. **20A**, brightness of a “0” gray level is increased more than that of a “95” gray level near about 50° in left/right directions. Also, as shown in FIG. **20B**, brightness of a “255” gray level is decreased more than that of a “223” gray level, and brightness of a “191” gray level is decreased more than that of a “63” gray level, near about 20° to 30° in upper/lower directions.

**[0080]** As shown in FIG. **19B**, the in-plane switching mode liquid crystal display device according to the present invention can obtain contrast ratio of 100 at an inclination angle 40° for azimuth angles 45°, 135°, 225°, and 315°, and can obtain contrast ratio of 10 at an inclination angle 70°. Moreover, since the viewing angle is symmetric in the upper/lower/left/right directions, the range of upper/lower/left/right viewing angles is wide. In other words, the present in-plane switching mode liquid crystal display device has a relatively wider viewing angle and has a higher contrast ratio compared to the

general twisted nematic mode liquid crystal display device. Furthermore, since a color coordinate in the in-plane switching mode liquid crystal display device is located adjacently with a coordinate of standard white light ( $[x,y]=[0.329,0.333]$ ) as shown in FIG. 21, adjustment of the white balance is easy.

**[0081]** As described above, in the in-plane switching mode liquid crystal display device, the method of fabricating the same, and the method of driving the same, each of the first and the second ferroelectric liquid crystal layers formed in the upper and lower substrates, respectively, reacts to the electric fields of opposite polarities, so that the liquid crystal molecules of a nematic liquid crystal layer is driven under in plane switching. As set forth above, the first and the second ferroelectric liquid crystal layer react to the opposite polarity electric fields, thereby permitting a picture in the entire frame irrespective of the polarity of the voltage applied thereto. Further, the nematic liquid crystal material is in-plane switched by the ferroelectric liquid crystal layer and the phase difference of the ferroelectric liquid crystal layer is identical to that of a compensation film. Accordingly, it is possible to prevent light leakage generated in the lateral surface of the polarizing plate without using the compensation film.

**[0082]** Although the present invention has been explained by the embodiments shown in the drawings described above, it should be understood to the ordinary skilled person in the art that the invention is not limited to the embodiments, but rather that various changes or modifications thereof are possible without departing from the spirit of the invention. Accordingly, the scope of the invention shall be determined only by the appended claims and their equivalents.

What is claimed is:

1. A method of driving a liquid crystal display device having opposing substrates with opposing electrodes thereon and a multilayer liquid crystal layer disposed between the electrodes, the multilayer liquid crystal layer containing opposing layers of a first type of liquid crystal molecules and a middle layer there between of a second type of liquid crystal molecules, the method comprising:

applying an electric field to the opposing layers using the opposing electrodes; and  
in-plane driving liquid crystal molecules in the middle layer by permitting one of the opposing layers to react to the electric field.

2. The method according to claim 1, wherein the in-plane driving comprises permitting only one of the opposing layers to react to the electric field.

3. The method according to claim 2, wherein the in-plane driving comprises permitting the opposing layers to react to electric fields of different polarities.

4. The method according to claim 1, further comprising driving the opposing layers under half V-switching mode.

5. A method of fabricating an in-plane switching mode liquid crystal display device, the method comprising:

forming an electrode and a first liquid crystal layer on each of an upper and lower substrate;

exposing each first liquid crystal layer to an amphiphilic or amphiphobic medium;

stabilizing each of the exposed first liquid crystal layers in a mono-stable state; and

providing a second liquid crystal layer between the stabilized first liquid crystal layers.

6. The method according to claim 5, wherein the stabilizing comprises causing a phase transition of each first liquid crystal layer.

7. The method according to claim 6, wherein each first liquid crystal layer undergoes multiple phase transitions before the second crystal layer is provided between the first liquid crystal layers.

8. The method according to claim 7, wherein the stabilization occurs without an external electric field being applied to either of the first liquid crystal layers.

9. The method according to claim 5, further comprising applying a mixture of liquid crystal material and an organic solvent to each substrate and heating the substrate to a temperature sufficient to vaporize the organic solvent.

10. The method according to claim 9, further comprising cooling the liquid crystal material after the organic solvent is vaporized to produce a phase transition in the liquid crystal material.

11. The method according to claim 10, wherein the phase transition comprises from an isotropic phase to a chiral smectic C phase.

12. The method according to claim 11, wherein the phase transition further comprises a chiral nematic phase between the isotropic phase and the chiral smectic C phase.

13. The method according to claim 5, further comprising forming an alignment film on each of the substrates.

14. The method according to claim 13, wherein the alignment film includes an amphiphilic medium.

15. The method according to claim 13, wherein the alignment film includes a polyamic acid or a polyimide.

16. The method according to claim 13, further comprising exposing at least one of the first liquid crystal layers to a medium having a weaker polarity than the alignment film so that spontaneous polarization of the at least one of the first liquid crystal layers is directed toward the alignment film most proximate to the at least one of the first liquid crystal layers.

17. The method according to claim 16, wherein the medium having the weak polarity comprises air or nitrogen.

18. The method according to claim 5, wherein each of the first liquid crystal layers comprises a ferroelectric liquid crystal layer.

19. The method according to claim 5, wherein the second liquid crystal layer comprises a nematic liquid crystal layer.

20. The method according to claim 5, wherein each of the stabilized first liquid crystal layers have a phase difference value of 10 nm to 150 nm.

\* \* \* \* \*

|                |                                                              |         |            |
|----------------|--------------------------------------------------------------|---------|------------|
| 专利名称(译)        | 面内切换模式的液晶显示装置，其制造方法及其驱动方法                                    |         |            |
| 公开(公告)号        | <a href="#">US20090102993A1</a>                              | 公开(公告)日 | 2009-04-23 |
| 申请号            | US12/253546                                                  | 申请日     | 2008-10-17 |
| [标]申请(专利权)人(译) | 乐金显示有限公司                                                     |         |            |
| 申请(专利权)人(译)    | LG DISPLAY CO.LTD：                                           |         |            |
| 当前申请(专利权)人(译)  | LG DISPLAY CO.LTD：                                           |         |            |
| [标]发明人         | CHOI SU SEOK<br>PARK KU HYUN                                 |         |            |
| 发明人            | CHOI, SU SEOK<br>PARK, KU HYUN                               |         |            |
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| 其他公开文献         | US7808604                                                    |         |            |
| 外部链接           | <a href="#">Espacenet</a> <a href="#">USPTO</a>              |         |            |

#### 摘要(译)

面内切换模式液晶显示装置包括上基板和下基板，第一和第二铁电液晶层，向列系统晶体层，以及第一和第二电极。电极和液晶层位于基板之间，向列液晶层位于铁电液晶层之间。铁电液晶层具有不同的自发极化方向。使用电极将电场施加到液晶层。铁电液晶层对不同的电场起反应，以在向列液晶层中进行液晶分子的面内驱动。

