

Title of the Invention

LIQUID CRYSTAL DISPLAY APPARATUS

Background of the Invention

5

(1) Field of the Invention:

The present invention relates to a thin film transistor type liquid crystal display apparatus (hereinafter called TFT-LCD).

10

(2) Description of the Prior Art:

A method of liquid crystal display using a pair of comb-like electrodes is disclosed in PCT WO91/10936 as one of the methods wherein an electric field is applied to liquid crystal molecules in a direction approximately parallel to a boundary plane of the substrate (In-plane switching method). Liquid crystal display device using a combination of the in-plane switching method and the thin film transistor are disclosed in JP-B-63-21907 (1988), JP-A-6-160878 (1994), etc.

The in-plane switching method (parallel field switching mode) has a wide viewing angle, no inverse of gray scales, no decrease in contrast, and no deterioration of hue, because the liquid crystal molecules do not rise from a boundary plane of the substrate. However, the in-plane switching method has not been used in practical by the following reason;

A-0000128

In using the in-plane switching method, a pixel must be divided into, for instance, two or four subpixels via linear electrodes in order to apply an effective electric field to the liquid crystal molecules. In this case, because
5 of new addition of plural linear electrodes which are not existing in a method of liquid crystal display wherein an electric field is applied vertically to the boundary plane of the substrate (vertical field switching mode), a ratio of an effective area of transmitting light decreases
10 remarkably in comparison with the type wherein the electric field is applied vertically to the boundary plane of the substrate. Accordingly, if a same back light is used, the in-plane switching type display becomes darker than the vertical field switching mode display, and it is necessary
15 to increase an intensity of the back light if the same brightness is maintained. Therefore, power consumption of the in-plane switching type display increases remarkably.

In the in-plane switching method, the liquid crystal structure (characteristics of the liquid crystal material,
20 thickness of the liquid crystal layer, orientation of the liquid crystal molecules, location of polarizers, etc.) and the electrode structure (shapes of pixel portion, conductive material of wiring, semiconductor material, insulating material, etc.) must be changed significantly at
25 a same time. Furthermore, the liquid crystal structure and the electrode structure has a close relationship such as that if one of the structures is changed, another structure

of optimum state must be changed, and respective one of the structures can not be treated as a black box like the vertical electric field method. Additionally, in accordance with remarkable changes of the liquid crystal structure and the electrode structure, some portions which compose the pixel portions and the peripheral portions change remarkably in their electrical circuit constants. Therefore, a driving method must be determined in consideration of the typical circuit characteristics of the in-plane switching method. That means, all of the liquid crystal structure, the electrode structure, and the driving circuit are related mutually, no one can be regarded as a black box, and the above relationship makes designing of the in-plane switching method complex and difficult.

15

Summary of the Invention

(1) Objects of the Invention:

Object of the present invention is to provide an optimum combination of the liquid crystal structure, the electrode structure, and the driving method in order to obtain a TFT-LCD of the in-plane switching method having a wide viewing angle, a high contrast ratio, liquid crystal panels of high transmittance, preferable illumination, and low power consumption.

25

(2) Methods for solving the Problem:

The liquid crystal display device relating to the present invention comprises a pair of substrates, plurality of signal wiring electrodes and scanning wiring electrodes formed on the substrates, and a liquid crystal composition layer interposed between the pair of substrates, wherein plurality of the signal wiring electrodes and the scanning wiring electrodes form plurality of pixels by intercrossing like a matrix. In the pixel, active elements for switching on-off of pixel electrodes in the pixel are formed, and when the active element is turned on, an electric field is supplied between the pixel electrode and a reference electrode (for example, a common electrode) approximately in parallel to the substrate plane. A scanning wiring electrode driving circuit for supplying scanning signal having at least two values of non-selected voltage is connected to the scanning wiring electrode, and a signal wiring electrode driving circuit for supplying image signal is connected to the signal wiring electrode.

The liquid crystal composition layer and polarizing means are set so that the contrast ratio perpendicular to the substrate is to be at least 10, and illumination transmittance is to be at least 15 %, and the pixel electrode and the reference electrode desirably extend in a first direction which is parallel to the signal wiring electrode in a pixel.

Because the electrodes are composed so that an electric field in parallel to the substrate plane is supplied

to the liquid crystal composition, a wide viewing angle can be obtained. The contrast ratio and illumination transmittance are increased by combining the liquid crystal composition layer and the polarizing means as the liquid crystal structure. A high aperture ratio can be obtained by extending respective of the pixel electrode and the reference electrode in the first direction which is parallel to the signal wiring electrode in a pixel, and image quality failure such as smear can be suppressed even with electrode structure of the high aperture ratio by connecting the scanning wiring electrode to the scanning wiring electrode driving circuit which supplies the scanning signal having at least two values of non-selected voltage.

Furthermore, the non-selected voltage of the scanning signal which is supplied to the scanning wiring electrode desirably changes in all lines with a same frequency and a same phase. And synchronizing with the above change, a voltage waveform which changes with a same frequency and a same phase is desirably supplied to the common electrode during all through the period and to the pixel electrode in the non-selected period. The amplitude of the non-selected voltage of the scanning signal which is supplied to the scanning wiring electrode, the voltage supplied to the common electrode all through the period, and the voltage supplied to the pixel electrode during the non-selected period are desirably approximately same. In a pixel among the pixels, an interval D between the pixel electrode and the adjacent

reference electrode is desirably larger than $1/3$ of any of the widths W_p , W_c of said pixel electrode and said reference electrode. Dielectric anisotropy of the liquid crystal composition layer is positive, and an angle $|\phi_{LC}|$ formed by
 5 intercrossing the orientation direction of the liquid crystal molecules on at least one of substrate planes with the direction of the electric field is desirably in a range at least 45 degrees and less than 90 degrees. However, a condition, $-90 \text{ degrees} \leq \phi_{LC} \leq 90 \text{ degrees}$, must be satisfied.

10 Regarding to the orientation in the liquid crystal composition layer, the angle of the orientation direction of the liquid crystal molecules on the one of substrate planes, ϕ_{LC1} , and the angle of the orientation direction of the liquid crystal molecules on the another one of substrate
 15 planes, ϕ_{LC2} , are approximately parallel ($\phi_{LC1} \doteq \phi_{LC2}$) each other, and a product, $d\Delta n$, of thickness d of the liquid crystal composition layer and the anisotropy of refractive index, Δn , is desirably in a range between $0.21 \mu\text{m}$ and $0.36 \mu\text{m}$.

20 Definitions of an angle, ϕ_p , which is formed by polarizing transmittance axis with the electric field direction, an angle, ϕ_{LC} , which is formed by the direction of longitudinal axis of the liquid crystal molecules (the optical axis) in the vicinity of the boundary plane with
 25 the electric field direction, and an angle, ϕ_R , which is formed by the leading phase axis of the retardation film

inserted between the pair of the polarizers with the electric field direction are indicated respectively in FIG. 6. Respective of the polarizers and the liquid crystal boundary planes form a pair by the one at an upper position and the other at a lower position, and if necessary, they are expressed respectively as ϕ_{P1} , ϕ_{P2} , ϕ_{LC1} , ϕ_{LC2} .

FIG. 1 (a) and FIG. 1 (b) indicate respectively a cross sectional view illustrating schematically an operation of the liquid crystal molecules in the liquid crystal panel of the present invention, and FIG. 1 (c) and FIG. 1 (d) indicate respectively an elevational view of the same. In accordance with the present invention, a plurality of pixels are formed by composing a stripe-like electrode, but the above figures indicate only a part of the pixel. A schematic cross sectional view of a cell when no voltage is charged is shown in FIG. 1 (a), and a schematic elevational view of the same is shown in FIG. 1 (c). Linear electrodes 1, 2 are formed at inner planes of a pair of transparent substrates, and an orientation control film 4 is applied and treated for orientation thereon. A liquid crystal composition is interposed between the pair of the transparent substrates. The rod-like liquid crystal molecule 5 is oriented so as to have an angle in a range of to 45 degrees $\leq |\phi_{LC}| < 90$ degrees a direction of the longitudinal axis of the electrodes 1, 2 when no voltage is charged. Here, an example is explained by taking a case when the directions of the liquid crystal molecules orientation

at the upper boundary plane and the lower boundary plane are in parallel, that is $\phi_{LC1} = \phi_{LC2}$. In this case, the dielectric anisotropy of the liquid crystal composition is assumed as positive.

5 When an electric field 7 is supplied, the liquid crystal molecules change their direction in accordance with the electric field as shown in FIG. 1 (b) and FIG. 1 (d). Transmittance of light can be changed with supplying an electric field by arranging a polarizer 6 in a direction 9 of
10 the polarizing axis of the polarizer. In accordance with the present invention, a display giving contrast becomes possible with no existence of transparent electrodes as explained above. In the present invention, the case when the angle is equal to or less than 45 degrees is generally
15 called as an in-plane switching mode. In FIG. 1, the electrodes 1, 2 are formed on a same substrate. However, respective of the electrodes can be formed on each of the upper and the lower substrates without any change in their advantages. In consideration of the cases when wiring in a
20 pattern becomes finer than ever, and various deformation occur by heat, external force, etc., the electrodes are preferably formed on a same substrate because more precise alignment becomes possible than the other case wherein the electrodes are respectively formed on each of the
25 substrates. The dielectric anisotropy of the liquid crystal composition is assumed as positive, but if it may be negative, it does not cause any problem. In the case of

negative, the initial orientation condition is arranged so as to have an angle $|\phi_{lc}|$, (that is $0 \text{ degree} < |\phi_{lc}| \leq 45$ degrees) in a direction vertical to the longitudinal axis of the electrodes 1, 2 (the direction of the electric field
 5 7). In accordance with a display mode of the present invention, the longitudinal axis of the liquid crystal molecule is always approximately in parallel to the substrate, and no rise. Therefore, variation in brightness is small when the viewing angle is changed.

10 As for a practical composition to give the contrast, there are two modes. The one is a mode wherein the orientation of the liquid crystal molecules at the upper and the lower substrates are approximately in parallel (it is called a birefringence mode, because interference colors
 15 by the birefringence phase difference are utilized), and another is a mode wherein the orientation direction of the liquid crystal molecules at the upper and the lower substrates are intercrossed and the molecular arrangement in the cell is twisted (it is called a rotatory
 20 polarization mode, because the rotatory polarization, wherein the polarizing plane rotates in the liquid crystal composition layer, is utilized).

Generally, transmittance of light, T/T_0 , is expressed by the following equation when a monoaxial birefringence
 25 medium is interposed between two polarizers which are arranged so as to intercross perpendicularly;

$$T/T_0 = (\sin(2\chi_{\text{eff}}))^2 \cdot (\sin(\pi d_{\text{eff}} \cdot \Delta n / \lambda))^2 \dots (1)$$

Where,

χ_{eff} : A direction of an effective optical axis (an angle formed by the optical axis with the transmittance axis of the polarized light) of the liquid crystal composition layer,

d_{eff} : An effective thickness of the liquid crystal composition layer having birefringence,

Δn : A refractive index anisotropy, and

λ : A wavelength of light.

In the equation, the direction of the effective optical axis of the liquid crystal composition layer is used aiming at treating the liquid crystal molecules by an apparent value assuming an uniform condition having an average value, in consideration that the liquid crystal molecules are fixed on the boundary plane in the actual cell, and when an electric field is applied, all of the liquid crystal molecules in the cell are not oriented parallel nor uniformly. The orientation is deformed, especially a large deformation is caused in the vicinity of the boundary plane.

In order to obtain a negative contrast display, which performs a dark state by applying a low voltage V_L and a bright state by applying a high voltage V_H , for instance, polarizers must be arranged so that a transmittance axis (or an absorbing axis) of one of the polarizers is arranged in approximately parallel to the orientation direction (rubbing direction) of the liquid crystal molecules, that

means $\phi_{p1} \doteq \phi_{lc1} = \phi_{lc2}$, and the transmittance axis of another one of the polarizers is arranged perpendicularly to the above other transmittance axis, that means $\phi_{p2} = \phi_{p1} + 90$ degrees. The dark state having a sufficiently small

5 transmittance can be readily realized by intercrossing the two polarizers in right angles. However, the arrangement is not restricted to the intercrossing in right angles. When the electric field is not applied, the χ_{eff} in the equation (1) is zero, and the transmittance of light T/T_0 becomes

10 also zero. On the contrary, when the electric field is applied, the χ_{eff} value increases in accordance with the strength of the electric field, and the value becomes the maximum at 45 degrees. At that time, in order to make the transmittance maximum in a colorless condition with an

15 assumed light wave length of $0.555 \mu\text{m}$, the $d_{eff} \cdot \Delta n$ must be selected as $0.28 \mu\text{m}$, a half of the wave length. Practically, the $d_{eff} \cdot \Delta n$ can be set in a range from 0.21 to $0.36 \mu\text{m}$ because there is an allowance, but desirable in a range from 0.24 to $0.33 \mu\text{m}$.

20 On the other hand, in order to obtain a positive contrast display, which performs a bright state by applying a low voltage V_L and a dark state by applying a high voltage V_H , the polarizers must be arranged so that the χ_{eff} in the equation (1) becomes 45 degrees when the electric field is

25 not applied or a low electric field is applied. When the electric field is applied, the χ_{eff} value decreases in

accordance with the strength of the electric field reversely to the case of the negative contrast display. However, even if the χ_{eff} value becomes minimum, that is zero, not a small amount of light leaks on account of a residual phase difference of liquid crystal molecules which are fixed in the vicinity of the boundary plane. In accordance with experiments performed by the present inventor, wherein the $d \cdot \Delta n$ was set in a range from 0.27 to 0.37 μm and an effective voltage of 3-10 V was applied, it was revealed that values of the residual phase difference at the boundary were in a range from 0.02 to 0.06 μm . A relationship between an actual thickness of the liquid crystal composition layer d and an effective thickness of the liquid crystal composition layer d_{eff} is expressed by the following equation (2);

$$d_{\text{eff}} \cong d - R_s \quad \dots (2)$$

Therefore, the dark state is deepened and a high contrast ratio can be obtained by inserting a retardation film having a birefringence phase difference of approximately from 0.02 to 0.06 μm (this phase difference is expressed as R_r in the present specification) so as to compensate the residual phase difference at the boundary. An angle ϕ_r of the leading phase axis of the retardation film is set in parallel to the effective optical axis χ_{eff} of the liquid crystal composition layer when a voltage is applied. In order to deepen the dark state completely, the voltage for displaying the dark state must be adjusted

exactly with the residual phase difference when the voltage is applied. As explained above, in order to make the deep dark state and the transmittance and brightness of the bright state compatible, a relationship expressed by the following equations must be satisfied;

$$0.21 \text{ } \mu\text{m} < (d \cdot \Delta n - R_f) < 0.36 \text{ } \mu\text{m} \quad \dots (3)$$

And, desirably,

$$0.23 \text{ } \mu\text{m} < (d \cdot \Delta n - R_f) < 0.33 \text{ } \mu\text{m} \quad \dots (4)$$

The above explained method is especially effective for the liquid crystal having negative dielectric anisotropy, wherein the orientation directions (the directions of the optical axis of the liquid crystal molecules) in a sub-pixel become relatively uniform under a condition when an electric field is applied.

In accordance with the twisted nematic (TN) method, which is one of conventional methods, the high transmittance and the colorless condition can be obtained when the $d \cdot \Delta n$ is set at approximately $0.50 \text{ } \mu\text{m}$, i.e. a first minimum condition, as widely well known. In consideration of its allowance, the $d \cdot \Delta n$ must be set in a range from 0.40 to $0.60 \text{ } \mu\text{m}$ in the TN method.

In order to eliminate rotatory polarization completely, the orientation direction of the liquid crystal in the vicinity of the boundaries of the upper and the lower substrates must be in parallel, and assuming a case when a 90 degrees TN mode is used, the liquid crystal

molecules on the one of the substrates must be rotated by nearly 90 degrees. In a case when birefringence mode is used, the rotatory angle of the liquid crystal molecule can be approximately 45 degrees, and the threshold voltage in the birefringence mode becomes lower than that in the TN mode.

Furthermore, in accordance with the conventional art, it was necessary to use an orientation film providing a large declining angle (an angle formed by the longitudinal axis of the liquid crystal molecule with the boundary plane) and to maintain the angle precisely by controlling the process condition severely. However, in accordance with the present invention, it is not necessary to use such the orientation film nor to control the process condition severely. The role of the declining angle can be expressed in other words as follows; When an angle ϕ_{lc} formed by a direction of an electric field with an initial orientation direction of the liquid crystal molecule is 90 degrees, energy for deformation when the angle increases with increase of the electric field is similar with the energy for deformation when the angle decreases with increase of the electric field, and accordingly, both cases of increase and decrease are compatible, a domain for leaking light is generated at boundary of the above cases, and there is a possibility to reduce the contrast ratio. Therefore, it becomes possible to make select forcefully either one of cases to increase or decrease from 90 degrees by setting

the angle ϕ_{LC} at a shifted angle from 90 degrees
(substantially equal to or smaller than 89.5 degrees,
desirably equal to or smaller than 88 degrees). Instead of
providing the declining angle, the longitudinal direction
5 of the liquid crystal molecule (the direction of rubbing)
on the boundary plane of the substrate can be set to a
designated direction which is shifted from 90 degrees to
the direction of the electric field. For simplifying, the
above explanation has been described taking the liquid
10 crystal having a positive dielectric anisotropy as an
example, but a case when the liquid crystal having a
negative dielectric anisotropy is used, the designated
direction must be shifted from 0 degree. Especially, when
the dielectric anisotropy of the liquid crystal composition
15 is negative, an advantage that generation of the domain can
be prevented by adequate setting of the rubbing direction
is significant. That means, an angle ϕ_{LC} (ϕ_{LC} is defined as
larger than 0 degree) formed by a direction of an electric
field with the direction of the longitudinal axis of the
20 liquid crystal molecule on the boundary plane of the
substrate must be set more than 0 degree (substantially at
least 0.5 degrees), desirably at least 2 degrees.

Generally, control of the declining angle requires
high grade molecular design of the orientation film and
25 precise control of the mass production process (such as
application of the orientation film material, heat
treatment, etc.), and freedom of the usable material is

restricted. However, in accordance with the present invention, the role of the declining angle in a vertical electric field method can be provided by setting an adequate direction of the rubbing material, and accordingly, the freedom of selecting orientation film material can be increased. For instance, a flattening film on a color filter, or a passivation film (partially or totally) on a thin film transistor is formed of an organic polymer, and each of the above films can be concurrently used as an orientation film by surface orientation treatment such as directly rubbing etc. In accordance with use of the organic polymer, unevenness on the surface can be flattened, and optical leakage accompanied with disturbance of orientation in the vicinity of steps can be suppressed, and furthermore, an advantage to increase the contrast ratio can be obtained.

In accordance with the in-plane switching method, a plurality of slender linear electrodes are arranged, and the liquid crystal is driven by applying an electric potential between the electrodes. In this case, a practical aperture of at least more than 20 % can be obtained by arranging all of the linear electrodes in a pixel in approximately a specified direction (first direction), and setting an interval L between two adjacent linear electrodes to be at least $1/3$ of width W of the linear electrode.

Generally, when performing an active drive such as a

TFT method, it is necessary to store an electric charge in a liquid crystal element so as to supply a constant voltage to the liquid crystal continuously for a specified period. Therefore, in order to extend the voltage holding period, a liquid crystal material having a high specific electric resistance is used in forming the liquid crystal, and concurrently, for instance, a design is performed aiming at forming an auxiliary capacitance element in parallel so as to increase total stored amount of electric charge. Increase of total capacity of the liquid crystal element and the auxiliary capacitance element is also important in improving image quality. That is, the increase of the total capacity is effective as a countermeasure for preventing formation of undesirable and unnecessary circuit elements (called as a parasitic capacitance element) in view of electrodes wiring design. Because, in accordance with the increases of the total capacity of the liquid crystal element and the auxiliary capacitance element, the parasitic capacitance element becomes relatively negligible small.

In accordance with the vertical electric field method, respective of the pixel electrode and the common electrode has a transparent flat structure, and the above electrodes formed a large parallel flat plate capacitance (in the present specification, the capacitance formed between the pixel electrode and the common electrode is expressed as C_{LC}) by facing each other. Therefore, the capacitance C_{LC} of

the liquid crystal element was relatively large, and the total capacitance which was large enough for eliminating an effect of the parasitic capacitance element was obtained if the capacitance C_s was designed somewhat large. On the contrary, in accordance with the in-plane switching method, respective of the pixel electrode and the common electrode has a linear structure, and the capacitance C_{LC} is remarkably small in comparison with the vertical electric field method. Furthermore, on account of its linear structure of the electrodes, the resistance of the circuit is significantly large in comparison with the vertical electric field method even if the specific resistance is same, and accordingly, a required condition for the specific resistance is not severe in view of maintaining the necessary voltage. That means, the voltage can be maintained for a long time by combining with the high resistant circuit without increasing the capacitance C_s of the auxiliary capacitance element so large.

Liquid crystal materials having a resistance at least $10^{13} \Omega \cdot \text{cm}$ is necessary for the vertical electric field method, while, $10^{11} \Omega \cdot \text{cm}$ is sufficient for the in-plane switching method. In accordance with the in-plane switching method, if the small total capacity of $C_{LC} + C_s$ can be used skillfully, reducing the load to the whole panel can be achieved and making the power consumption of the circuit small can be realized. The moderate restricting condition for the specific resistance of the liquid crystal broadens

the freedom for selecting the liquid crystal materials.

Among the parasitic capacitance which caused a problem in the in-plane switching method, a capacitance (expressed as C_{gs}) formed between the scanning signal electrode (gate electrode) and the pixel electrode (source electrode) was found to be the most serious one. Therefore, a waveform, which enabled the liquid crystal to maintain a sufficient voltage in the liquid crystal, to operate sufficiently with the auxiliary capacitance element smaller than the vertical electric field method and to make the parasitic capacitance negligible, was searched. As a result, it has been revealed that relative differences of potentials among the scanning wiring electrode, the reference electrode, and the pixel electrode can be suppressed to low (approximately zero if the amplitude is same) during a non-selected period, which is nearly most of the total period, by applying a scanning signal having a non-selected voltage of at least two values, for instance, a rectangular wave of an alternating current composed of an aligned pulses of a constant width to respective of the scanning wiring electrodes, and applying an alternating current having the same phase and the same polarity as the above scanning signal is applied to the reference electrode (the common electrode) during all through the period and to the pixel electrode during the non-selected period. As the result, the parasitic capacitance became negligible.

Brief Description of the Drawings

These and other objects, features, and advantages of the present invention will be understood more clearly from the following detailed description with reference to the accompanying drawings, wherein;

FIGs. 1(a) and 1(b) are schematic illustrations indicating an operation of the liquid crystal molecule in the liquid crystal display apparatus relating to the present invention,

FIG. 2 is a schematic partial cross sectional view indicating an example of structure of the thin film transistor and the electrode of the present invention,

Fig. 3 is an example of a set of driving waveforms relating to the present invention,

FIG. 4 is a schematic illustration indicating an equivalent circuit in a pixel of the present invention,

FIG. 5 is another example of a set of driving waveforms relating to the present invention,

FIG. 6 is an illustration indicating the angles formed by respective of an orientation direction of the longitudinal axis of the liquid crystal molecule on a boundary plane ϕ_{LC} , a polarizing axis of the polarizer ϕ_p , and a leading phase axis of the retardation film ϕ_R , with the direction of the electric field,

FIG. 7 is a graph indicating electro-optical characteristics in various embodiments, wherein the orientation direction of the longitudinal axis of the

liquid crystal molecule on a boundary plane ϕ_{lc} is varied in the respective embodiment, and the dielectric anisotropy is positive,

FIG. 8 is a schematic illustration indicating a driving
5 circuit system of the liquid crystal display apparatus relating to the present invention,

FIG. 9 is a schematic illustration indicating a transmission optical system of the liquid crystal display apparatus relating to the present invention,

10 FIG. 10 is a schematic illustration indicating a reflection optical system of the liquid crystal display apparatus relating to the present invention,

FIG. 11 is a graph indicating electro-optical characteristics in various embodiments, wherein the
15 orientation direction of the longitudinal axis of the liquid crystal molecule on a boundary plane ϕ_{lc} is varied in the respective embodiment, and the dielectric anisotropy is negative,

FIGs. 12(a) and 12(b) are graphs indicating electro-
20 optical characteristics in various embodiments, wherein the thickness d of the liquid crystal composition layer is varied in the respective embodiment, and the dielectric anisotropy is negative,

FIGs. 13(a) and 13(b) are graphs indicating electro-
25 optical characteristics in various embodiments, wherein the polarizer is arranged so that the dark state is obtained by setting the electric field not zero but in a somewhat charged

condition,

FIG. 14 is a graph indicating characteristics of the positive contrast display and the characteristics when the residual phase difference at the boundary plane is

5 compensated,

FIG. 15(a) is a schematic plan view of the fourth embodiment of the present invention, wherein a capacitance element is formed between the common electrode and the pixel electrode which are provided on the counter
10 substrates, 15(b) is a cross section taken along the line A-A' in FIG. 15(a), and 15(c) is a cross section taken along the line B-B' in FIG. 15(a),

FIG. 16 is a schematic plan view of a pixel in the fifth embodiment of the present invention, wherein the
15 pixel electrode and the common electrode are separated into two layers by inserting an insulating layer between the above two electrodes, and no electric field is applied,

FIG. 17 is a cross section taken along the line A-A' in FIG. 16,

20 FIG. 18 is a schematic plan view of a pixel in the sixth embodiment of the present invention, wherein the pixel electrode is shaped a ring, the common electrode is shaped a cruciform, the pixel electrode and the common electrode are separated into two layers by inserting an
25 insulating layer between the above two electrodes, and no electric field is applied,

FIG. 19 is a schematic plan view of a pixel in the

seventh embodiment of the present invention, wherein the pixel electrode is shaped an I-character shape, the common electrode is shaped a ring, the pixel electrode and the common electrode are separated into two layers by inserting
5 an insulating layer between the above two electrodes, and no electric field is applied,

FIG. 20 is a schematic cross sectional view of a pixel in the eighth embodiment of the present invention, wherein the pixel electrode and the common electrode are separated
10 into two layers by inserting an insulating layer between the above two electrodes, further another insulating layer is inserted between the scanning wiring electrode and the common electrode, and no electric field is applied,

FIG. 21 is a schematic cross sectional view of a pixel
15 in the ninth embodiment of the present invention, wherein the pixel electrode and the common electrode are separated into two layers by inserting an insulating layer between the above two electrodes, the common electrode is formed on a protective insulating film, and no electric field is
20 applied, and

FIG. 22 is a schematic cross sectional view of a pixel in the tenth embodiment of the present invention, wherein the pixel electrode and the common electrode are separated into two layers by inserting an insulating layer between
25 the above two electrodes, both the scanning wiring electrode and common electrode are composed of aluminum which is coated with a self-oxidized film, and no electric field is applied.

[Explanation of the marks]

1...pixel electrode (source electrode), 2...reference
 electrode, 3...substrate, 4...orientation film, 5...a
 liquid crystal molecule in the liquid crystal composition
 5 layer, 6...polarizer, 7...a direction of the electric
 field, 8...an orientation direction of the longitudinal
 axis of the liquid crystal molecule on the boundary plane
 (a rubbing direction), 9...a direction of the polarizing
 axis of the polarizer, 10...scanning wiring electrode,
 10 11...auxiliary (additional) capacitance element,
 12...signal wiring electrode, 13...gate insulating film,
 14...flattening film, 15...protective insulating film,
 16...amorphous silicon, 17...color filter, 18...shielding
 layer, 19...polarizing transmittance axis of polarizer,
 15 20...leading axis of retardation film, 21...signal wiring
 electrode driving circuit, 22...scanning wiring electrode
 driving circuit, 23...signal wiring electrode, 24...
 scanning wiring electrode, 25...lower substrate, 26...upper
 substrate, 27...control circuit, 28...retardation film,
 20 29...back light, 30...reflector, 31...liquid crystal
 composition layer, 32...alumina film, 33...base plate
 insulating film, 34...thin film transistor element,
 35...image information signal source, 36...common electrode
 driving circuit, 37...display region, and 38...a boundary
 25 of shielding layer.

Description of the Preferred Embodiments

(Embodiment 1)

Two glass plates of 0.7 mm thick are used as the substrates. A nematic liquid crystal composition is interposed between the substrates, wherein the nematic liquid crystal composition has a positive dielectric anisotropy $\Delta\epsilon$ of 4.5 and a refractive index anisotropy Δn of 0.072 (589 nm, 20 °C). Polyimide group orientation control film, which is applied on surface of the substrate facing to TFT, is processed with rubbing treatment to obtain a pretilt angle of 3.5 degrees. The rubbing directions at upper boundary and lower boundary were approximately in parallel each other, and an angle formed by the rubbing direction with a direction of applied electric field was set at 78 degrees ($\phi_{LC1} = \phi_{LC2} = 78^\circ$). A gap d between the substrates was maintained by interposing dispersed spherical polymer beads in 4.0 μm with the interposed liquid crystal. Therefore, $d \cdot \Delta n$ is 0.288 μm . A panel was held between two polarizers, wherein a polarizing transmittance axis of the one of the polarizers was approximately in parallel to the rubbing direction, that is $\phi_{P1} = 78^\circ$, and the polarizing transmittance axis of the other polarizer was approximately perpendicular to the rubbing direction, that is $\phi_{P2} = -12^\circ$. In accordance with the above procedure, a negative contrast characteristics was obtained.

FIG. 2 indicates structures of thin film transistors and various electrodes. In FIG. 2, a thin film transistor 34 is connected to a pixel electrode (source electrode) 1, a

signal wiring electrode 12, and a scanning wiring electrode 10, and the pixel electrode 1 and a reference electrode 2, which is a common electrode, extend in a parallel direction (called as a first direction) to the signal wiring electrode 12 in a pixel. In the present embodiment, both the pixel electrode 1 and the reference electrode 2 were set in parallel to the signal wiring electrode 12. However, even if any of the pixel electrode 1 and the reference electrode 2 are tilted somewhat (for instance, nearly 5 degrees) in order to control the threshold characteristics of the liquid crystal, the liquid crystal can be regarded as in the scope of the present invention, and advantages of the present invention can be sufficiently realized.

Furthermore, in accordance with the present embodiment, the reference electrode 2 was used as a reference electrode. However, not only based on image information, any electrode (for instance, a scanning wiring electrode) which is capable of supplying a constant predetermined waveform can be used as the reference electrode.

A signal waveform having image information is applied to the signal wiring electrode 12, and a scan waveform is applied to the scanning wiring electrode 10 synchronously with the signal waveform. An information signal is transmitted from the signal wiring electrode 12 to the pixel electrode 1 via the thin film transistor, and a voltage is applied to the liquid crystal between the reference electrode 2. In accordance with the present

embodiment, the pixel electrode 1 and the reference electrode 2 were arranged on the same substrate and formed in the same layer with the scanning wiring electrode 10. However, the structure is not restricted to the above described example, but also respective of the pixel electrode 1 and the reference electrode 2 may be arranged on the countersubstrate, and may be formed in the same layer with the signal wiring electrode 12 on the same substrate. Furthermore, a conductive layer for the reference electrode may be formed separately from the other electrodes to make a pattern.

The auxiliary capacitance element 11 was formed, as shown in FIG. 2, in a structure wherein a special region for arranging the auxiliary capacitance element was not formed, but an insulating film was interposed between a part of the pixel electrode 1 and the reference electrode 2 utilizing their wiring portion. Static capacitance of the auxiliary capacitance element 11 was approximately 21 fF. Respective of a scan wiring driving LSI and a signal wiring driving LSI was connected to the scanning wiring electrode 10 and the signal wiring electrode 12, respectively.

The electric charge accumulated in the pixel electrode 1 is further accumulated to approximately 24 fF, which is a capacitance obtained by connecting in parallel of the static capacitance between the pixel electrode 1 and the reference electrode 2 and the auxiliary capacitance element 11. Accordingly, voltage fluctuation of the pixel electrode 1

can be suppressed even if the specific resistance of the liquid crystal composition is $5 \times 10^{10} \Omega\text{cm}$. Therefore, deterioration of the image quality could be prevented.

The number of the pixels was 640 (X 3) X 480, and
5 pitch of the pixel was 110 μm in the horizontal direction
(that is an interval between the mutual common electrodes)
and 330 μm in the vertical direction (that is an interval
between the mutual scanning wiring electrodes). An interval
between the pixel electrode and the adjacent reference
10 electrode was set as 12 μm , which was sufficiently larger
than 1/3 of the widths of the pixel electrode and the
reference electrode, i.e. both 12 μm , and a practical
aperture ratio such as 33 % could be maintained. In
accordance with the present embodiment, one pixel was
15 divided into four rectangular sub-pixels. However, the
number of the division can be 2, 6, and zero. Further, a
plurality of both the pixel electrodes and the reference
electrodes were formed in the present embodiment, and the
widths of the electrodes can be altered for the plural
20 pixel electrodes mutually, or the plural reference
electrodes mutually. Furthermore, the widths of the single
pixel electrode or the single reference electrode can be
altered in itself.

Stripe shaped color filters 17 of three primary colors
25 such as red, green, and blue were arranged on the surface
of the substrate which was countered to the substrate which
was provided with the thin film transistor (FIG. 9). The

surface of the color filters was coated with a flattening film 14 composed of a transparent resin for flattening the surface. As material for the above transparent resin, an epoxy resin was used. Furthermore, an orientation

5 controlling film composed of a polyimide group resin was applied on the transparent resin, and processed with a rubbing treatment so as to have a pretilt angle of 10 degrees. In the present embodiment, the number of the kinds of the color filters was three, but two or more than three

10 kinds of filters could be used. Furthermore, in accordance with the present embodiment, the color filters and a black matrix were formed on the substrate countered to the substrate which was provided with the thin film transistor. However, one of or both the color filters and the black

15 matrix can be formed on the substrate whereon the thin film transistor is arranged.

Driving circuits are connected to the panel. A composition of the driving circuit system of the present embodiment is shown in FIG. 8. Driving waveforms of the

20 composition is shown in FIG. 3. The unselected voltage V_{gr} of the scan signal which applied to the scanning wiring electrode takes two values, and the values change in all the row at a cyclic period and a phase. In synchronizing with the waveform, the voltage waveform which varies with

25 the same cyclic period and the same phase is applied to the common electrode all over the cyclic period and to the pixel electrode during the unselected period. In accordance with

the above described waveform design, the voltage applied to the parasitic capacitance C_{gs} shown in FIG. 4 can be controlled, and the influence of the parasitic capacitance can be reduced. The amplitudes of the voltage waveforms which change at the same cyclic period and the same phase are ideal when they are similar magnitudes, and the voltage applied to the parasitic capacitance C_{gs} can be controlled most effectively. However, even if the amplitudes are not similar magnitudes, the advantage can be realized.

10 A contrast ratio of 130 and a brightness transmittance of 22 % could be obtained by driving the liquid crystal display apparatus with a voltage between 2 V and 6.5 V. The brightness transmittance referred in the present invention is defined as a value of brightness when the aperture is 15 100 % and the value is normalized as no color filters. The brightness transmittance at the bright state when the TFT-CLD including the color filters was driven was 2.2 %. A surface brightness of 80 cd/m² was obtained by overlapping a back light composed of a white fluorescent lamp and a light 20 guide plate. Power consumption of the back light was 6.4 W. Power consumption of the driving circuit was 1.2 W, and the total power consumption of the TFT-CLD became 7.6 W, which was sufficiently lower value than the power consumption of a CRT. The display characteristics hardly changed even if 25 the viewing angle was altered.

(Embodiment 2)

The present embodiment is the same as the embodiment 1

except a point wherein the driving waveform is changed as shown in FIG. 5. The two value unselected voltages V_{GL} of the scan signal which applied to the scanning wiring electrode changes at every selection of a line in the embodiment 1, but it changes at every frame in the present embodiment.

A contrast ratio of 110 and a brightness transmittance of 22 % were obtained by driving the liquid crystal display apparatus with a voltage between 2 V and 6.5 V. The brightness transmittance at the bright state when the TFT-CLD including the color filters was driven was 2.2 %. A surface brightness of 80 cd/m² was obtained by overlapping a back light composed of a white fluorescent lamp and a light guide plate. Power consumption of the back light was 6.4 W. Power consumption of the driving circuit was 1.2 W, and the total power consumption of the TFT-CLD became 7.6 W. The display characteristics hardly changed even if the viewing angle was altered.

(Embodiment 3)

The present embodiment is the same as the embodiment 1 except the following condition;

The interval d between the pixel electrode and the adjacent reference electrode was set as 8 μm , which was sufficiently larger than 1/3 of the widths of the pixel electrode and the reference electrode, i.e. both 13 μm , and a practical aperture ratio such as 26 % could be maintained.

The display characteristics hardly changed even if the viewing angle was altered. A contrast ratio of 110 and a brightness transmittance of 21 % were obtained by driving the liquid crystal display apparatus with a voltage between 1.3 V and 4.5 V. The brightness transmittance at the bright state when the TFT-CLD including the color filters was driven was 1.8 %. A surface brightness of 80 cd/m² was obtained by overlapping a back light composed of a white fluorescent lamp and a light guide plate. Power consumption of the back light was 8.1 W. Power consumption of the driving circuit was 1.2 W, and the total power consumption of the TFT-CLD became 9.3 W, which was sufficiently lower value than the consumption power of a CRT.

(Embodiment 4)

The present embodiment is the same as the embodiment 1 except the following condition;

FIG.15(a) is a partial plan view of the active matrix type liquid crystal display apparatus relating to the present embodiment. FIG. 15(b) is a cross section taken along the line A-A' in FIG. 15(a), and FIG. 15(c) is a cross section taken along the line B-B' in FIG. 15(a). The auxiliary capacitance element 11 shown in FIG. 1 was changed in its structure as shown in FIG. 15(c), wherein the liquid crystal composition layer 50 was held between the pixel electrode 1 and the reference electrode which was arranged on the counter substrate. In accordance with the present embodiment, it becomes possible to connect

completely in parallel the static capacitance of the auxiliary capacitance element 11 to the static capacitance between the pixel electrode 1 and the reference electrode 2, and accordingly, any influence of voltage fluctuation of the signal wiring electrode 12 does not reach the pixel electrode 1. Therefore, the voltage fluctuation of the pixel electrode 1 could be suppressed further, and display variation did not occur.

The liquid crystal display apparatus of the present embodiment did not generate any deterioration of the image quality, and a wide viewing angle as same as the embodiment 1 and a low power consumption less than 10 W were realized. (Embodiment 5)

The embodiments from 5 to 10 were same as the embodiment 1 except the conditions especially pointed out hereinafter.

FIGs. 16 and 17 are a plan view and a cross sectional view of an unit pixel of the present embodiment, wherein the pixel electrode 1 and the reference electrode 2 are arranged on mutually different layers separated by an insulating layer. The scanning wiring electrode 10 and the reference electrode 2 composed of Cr were formed on a glass substrate, and a gate insulating film 13 composed of silicon nitride (SiN) was formed so as to coat the above described electrodes. An amorphous silicon (a-Si) film 16 was formed on a part of the scanning wiring electrode 10 via the gate insulating film 13 as an active layer of the

transistor. The signal wiring electrode 12 and the pixel electrode 1 composed of Mo were formed so as to overlap a part of the pattern of the a-Si film 16, and a protective insulating film 15 composed of SiN film was formed so as to coat all of the above described members. When the thin film transistor is turned on by supplying a voltage to the scanning wiring electrode 13 of the transistor, a voltage is supplied to the pixel electrode 1, an electric field is induced in an interval between the pixel electrode 1 and the reference electrode 2, the liquid crystal molecules are oriented to the direction of the electric field as same as the previous embodiments, and transmittance of light is changed.

In accordance with the separation of the pixel electrode 1 and the signal wiring electrode 12 from the reference electrode 2, freedom in plane pattern designing of the pixel electrode 1 and the reference electrode 2 increases, and it becomes possible to increase an aperture of the pixel. The overlapping portion of the pixel electrode 1 and the reference electrode 2 operates as an additive capacitance connected in parallel to the capacitance of the liquid crystal, and it becomes possible to increase a holding capacity of the liquid crystal applied voltage. The above described advantages can not be obtained by a conventional comb-like shaped electrode, but can be achieved only by separating the pixel electrode 1 and the signal wiring electrode 12 from the reference

electrode 2. As FIG. 16 shows, it is not necessary to form the capacitance element by assigning a part of the display portion as is the case when the pixel electrode and the common electrode are arranged in a same layer, but it is only necessary to overlap a part of wiring for extending the common electrode toward outside the display region.

The liquid crystal display apparatus of the present embodiment did not generate any deterioration of the image quality, and a wide viewing angle as same as the embodiment 1 and a low power consumption less than 10 W were realized. (Embodiment 6)

FIG. 18 indicates a plan view of an unit pixel of the present embodiment, wherein the pixel electrode 1 and the reference electrode 2 were arranged on mutually different layers which were separated by an insulating layer. Feature of the present embodiment was in a fact that the reference electrode 2 had a cruciform shape, and the pixel electrode 1 had a ring-shape. The reference electrode 2 and the pixel electrode 1 were overlapped each other to form an additional capacitance. In accordance with the present embodiment, a distance between the reference electrode 2 and the scanning wiring electrode 10 can be taken large so as to prevent a shortage accident of the circuit between the reference electrode 2 and the scanning wiring electrode 10. Owing to the ring shaped pixel electrode, even if a breakage of wiring occurs at any arbitrary location of the source electrode, power can be supplied to whole the source

electrode as far as the breakage is less than two points, and a normal operation can be continued. That means, the structure of the present embodiment has a redundancy to the circuit breakage, and a production yield can be increased.

5 Owing to the redundancy, it becomes possible to make the width of the wiring of the ring shaped electrode, to arrange closely the wiring of the ring shaped electrode and the scanning wiring electrode, and to increase the aperture ratio.

10 The liquid crystal display apparatus of the present embodiment did not generate any deterioration of the image quality, and a wide viewing angle as same as the embodiment 1 and a low power consumption less than 10 W were realized.

15 (Embodiment 7)

FIG. 19 indicates a plan view of an unit pixel of another embodiment of the present invention, wherein the pixel electrode 1 and the reference electrode 2 were arranged on mutually different layers which were separated
20 by an insulating layer. Feature of the present embodiment was in a fact that the pixel electrode 1 had a I-letter shape and the reference electrode 2 had a ring shape. In accordance with the present embodiment, the aperture ratio can be increased as same as the embodiment 6, and
25 additionally, the overlapping portion of the pixel electrode 1 and the reference electrode 2 can be increased. Therefore, the additional capacitance can be increased.

The liquid crystal display apparatus of the present embodiment did not generate any deterioration of the image quality, and a wide viewing angle as same as the embodiment 1 and a low power consumption less than 10 W were realized.

(Embodiment 8)

FIG. 20 indicates a cross sectional view of an unit pixel of the present embodiment, wherein the pixel electrode 1 and the reference electrode 2 were arranged on mutually different layers which were separated by an insulating layer. In accordance with the present embodiment, the reference electrode 2 was composed of a new electrode, which was arranged on a layer beneath the scanning wiring electrode 10 via a base insulating film 33. Accordingly, the reference electrode 2 was arranged on a layer which was separated from all of the scanning wiring electrode, the pixel electrode 1, and the signal wiring electrode 12. Therefore, it becomes possible to withdraw the reference electrode 2 not only in a direction in parallel to the scanning wiring electrode 10 but also in a direction perpendicular to the scanning wiring electrode 10 for making a net work structure. Accordingly, the resistance of the reference electrode 2 can be decreased, and an advantage to reduce deformation of waveform of the common voltage and to prevent generation of smear can be achieved.

The liquid crystal display apparatus of the present

embodiment did not generate any deterioration of the image quality, and a wide viewing angle as same as the embodiment 1 and a low power consumption less than 10 W were realized.

5 (Embodiment 9)

FIG. 21 indicates a cross sectional view of an unit pixel of the present embodiment, wherein the pixel electrode 1 and the reference electrode 2 were arranged on mutually different layers which were separated by an
10 insulating layer. In accordance with the present embodiment, the reference electrode 2 was composed of a new electrode, which was arranged on the protective insulating layer 15. In the present embodiment, the reference electrode 2 was arranged on a layer which was separated from all of
15 the scanning wiring electrode, the pixel electrode 1, and the signal wiring electrode 12 as same as the embodiment 8. Therefore, it becomes possible to withdraw the reference electrode 2 not only in a direction in parallel to the scanning wiring electrode 10 but also in a direction
20 perpendicular to the scanning wiring electrode 10 for making a net work structure. Accordingly, the deformation of waveform of the common voltage can be reduced and the generation of smear can be prevented.

The liquid crystal display apparatus of the present
25 embodiment did not generate any deterioration of the image quality, and a wide viewing angle as same as the embodiment 1 and a low power consumption less than 10 W were realized.

(Embodiment 10)

FIG. 22 indicates a cross sectional view of an unit pixel of another embodiment of the present invention, wherein the pixel electrode 1 and the reference electrode 2 were arranged on mutually different layers which were separated by an insulating layer. Feature of the present embodiment was in a fact that the scanning wiring electrode 10 and the reference electrode 2 were composed of aluminum (Al), and their surfaces were coated with alumina film 32, which was a self oxidized film of aluminum. In accordance with use of such an insulating film having a double layers structure, failures of insulation among the reference electrode 2, signal wiring electrode 12, and the pixel electrode can be reduced, and consequently, defects of the pixel can be decreased.

The liquid crystal display apparatus of the present embodiment did not generate any deterioration of the image quality, and a wide viewing angle as same as the embodiment 1 and a low power consumption less than 10 W were realized.

(Embodiment 11)

The composition of the present embodiment is same as the embodiment 1 except the following condition;

A flattening film 14 composed of a transparent polymer was coated on a color filter as an organic insulating layer, and surface of the flattening film was directly processed with a rubbing treatment. As a material for the

transparent polymer, an epoxy resin was used. A liquid crystal composition layer was directly contacted with the epoxy resin, and a tilt angle at the boundary was 0.5 degrees. Accordingly, a process for applying an orientation film could be omitted, and manufacturing processes became easy and short. Generally in conventional TN type liquid crystal, various characteristics were required for an orientation control film, and all of the requirement must be fulfilled. Therefore, materials for the orientation control film were restricted to limited materials such as polyimide and the like. The most important characteristics is the tilt angle.

Electro-optical characteristics of the present embodiment were measured, and such a result was obtained that the display characteristics hardly changed even if viewing angles were altered in directions as left and right, and up and down. In spite of the small tilt angle such as 0.5 degrees, the orientation of the liquid crystal was preferable, and no orientation failure domain was generated. A low power consumption less than 10 W was realized.

(Embodiment 12)

The material for the flattening film in the embodiment 11 was altered from epoxy resin to polyimide resin. Surface of the polyimide resin is directly processed with a rubbing treatment as same as the embodiment 11 to provide both functions such as flattening and orientation control of the

liquid crystal molecules. The tilt angle at the boundary was 2 degrees. In comparison with other embodiments, the display characteristics was almost same. The orientation of the liquid crystal was preferable, and no orientation failure domain was generated.

(Embodiment 13)

The composition of the present embodiment is same as the embodiment 1 except the following condition;

The protective insulating film 15 for protecting the thin film transistor was altered from silicon nitride to an organic insulating layer composed of an epoxy resin, and surface of the protective insulating film 15 was directly processed with a rubbing treatment to provide the organic insulating layer with both functions as a protecting film and an orientation control film of the liquid crystal molecules. The tilt angle was 0.5 degrees.

Electro-optical characteristics of the present embodiment were measured, and a result which was almost same as the embodiment 1 was obtained. In spite of the small tilt angle such as 0.5 degrees, the orientation of the liquid crystal is preferable, and no orientation failure domain was generated.

The liquid crystal display apparatus of the present embodiment did not generate any deterioration of the image quality, and a wide viewing angle as same as the embodiment 1 and a low power consumption less than 10 W were realized.

(Embodiment 14)

The epoxy resin used for the protective insulating film
15 was changed to a polyimide resin which was the organic
insulating layer as well.

Electro-optical characteristics of the present
5 embodiment were measured, and a result which was almost
same as the embodiment 1 was obtained. The tilt angle was
slightly increased to 2.0 degrees. The orientation of the
liquid crystal was preferable, and no orientation failure
domain was generated.

10 The liquid crystal display apparatus of the present
embodiment did not generate any deterioration of the image
quality, and a wide viewing angle as same as the embodiment
1 and a low power consumption less than 10 W were
realized.

15 (Embodiments 15-19)

The composition of the present embodiment is same as
the embodiment 1 except the following condition;

In accordance with the embodiment 15, the direction of
the longitudinal axis of the liquid crystal molecules
20 (rubbing direction) at respective of the upper and the lower
boundary planes were approximately in parallel each other,
and the angle formed with the direction of the applied
electric field were set as 89.5 degrees ($\phi_{LC1} = \phi_{LC2} = 89.5^\circ$
) , the polarizing light transmittance axis of one of the
25 polarizers was set in a direction approximately in parallel
to the rubbing direction ($\phi_{p1} = 89.5^\circ$), and the polarizing
light transmittance axis of another polarizer was set

perpendicularly to the above polarizing light transmittance axis ($\phi_{P2} = -0.5^\circ$).

Similarly in embodiment 16, the above directions were set as follows;

5 $\phi_{LC1} = \phi_{LC2} = \phi_{P1} = 88^\circ$, $\phi_{P2} = -2.0^\circ$

Similarly in embodiment 17, the above directions were set as follows;

$$\phi_{LC1} = \phi_{LC2} = \phi_{P1} = 75^\circ$$
 , $\phi_{P2} = -15^\circ$

10 Similarly in embodiment 18, the above directions were set as follows;

$$\phi_{LC1} = \phi_{LC2} = \phi_{P1} = 45^\circ$$
 , $\phi_{P2} = -45^\circ$

Similarly in embodiment 19, the above directions were set as follows;

$$\phi_{LC1} = \phi_{LC2} = \phi_{P1} = 30^\circ$$
 , $\phi_{P2} = -60^\circ$

15 Results of measurements on the electro-optical characteristics in respective of the present embodiments are shown in FIG. 7. The brightness in FIG. 7 is expressed by normalized values taking the largest brightness as 100 % when a voltage in a range from zero to 10 volts (effective
20 voltage V_{rms}) was applied, and the minimum brightness as 0 %.. The curves of the threshold characteristics in FIG. 7 indicates a trend to be steep with increasing the angle ϕ_{LC} . Therefore, in order to perform a medium gray scale display with a sufficient voltage margin, ϕ_{LC} must be decreased.
25 However, when the ϕ_{LC} became equal to or less than 45 degrees, the brightness indicated a trend to decrease. The

optimum value for the angle ϕ_{LC} varies depending on the number of the medium gray scales to be displayed, the required value for the brightness, the driven voltage, and whether any voltage is applied to the common electrode or not. A designer can control the threshold characteristics in a wide range by selecting a suitable angle ϕ_{LC} . In consideration of the brightness, selection of an angle ϕ_{LC} equal to or larger than 45 degrees is desirable. Furthermore, an angle ϕ_{LC} in a range from 60 degrees to 88 degrees is preferable.

The results obtained in the measurement of viewing angle characteristics on the respective cases, wherein the viewing angle were varied in a direction horizontally or vertically as same as the embodiment 1, indicated that no significant difference existed mutually and the display characteristics hardly changed. The orientation of the liquid crystal was preferable, and no orientation failure domain was generated. A low power consumption less than 10 W was realized.

20 (Embodiments 20-23)

The largest difference of the present embodiments from the previous embodiments is in a point that the dielectric anisotropy of the liquid crystal composition layer is negative, and the rubbing direction was altered corresponding to the change of the dielectric anisotropy. A nematic liquid crystal composition (made by Merck Co., ZLI-2806), of which $\Delta\epsilon$ is -4.8, and Δn is 0.0437 (589 nm, 20°C

), was used. In accordance with the embodiments 20-23, the direction of the longitudinal axis of the liquid crystal molecules (rubbing direction, ϕ_{LC1} , ϕ_{LC2}) at respective of the upper and the lower boundary planes were approximately in parallel each other ($\phi_{LC1} = \phi_{LC2}$), and the angle, ϕ_{LC1} , formed with the direction of the applied electric field was set in a range larger than zero degree and less than 45 degrees. The polarizing light transmittance axis (ϕ_{P1}) of one of the polarizers was set in a direction approximately in parallel to the rubbing direction, and The polarizing light transmittance axis (ϕ_{P2}) of another polarizer was set perpendicularly to the above polarizing light transmittance axis.

That is, in embodiment 20, the above directions were set as follows;

$$\phi_{LC1} = \phi_{LC2} = \phi_{P1} = 1.5^\circ, \phi_{P2} = -88.5^\circ$$

In embodiment 21, the above directions were set as follows;

$$\phi_{LC1} = \phi_{LC2} = \phi_{P1} = 15^\circ, \phi_{P2} = -75^\circ$$

In embodiment 22, the above directions were set as follows;

$$\phi_{LC1} = \phi_{LC2} = \phi_{P1} = 30^\circ, \phi_{P2} = -60^\circ$$

In embodiment 23, the above directions were set as follows;

$$\phi_{LC1} = \phi_{LC2} = \phi_{P1} = 45^\circ, \phi_{P2} = -45^\circ$$

The gap d was set at 6.3 μm in a condition enclosing

the liquid crystal, and $\Delta n \cdot d$ was 0.275 μm . Other conditions of the structure of the thin film transistor and the electrodes than the above described items were as same as the condition of the embodiment 3.

5 Results of measurements on the electro-optical characteristics in respective of the present embodiments are shown in FIG. 11. The brightness in FIG. 11 was expressed by normalized values taking the brightness as 100 % when the two polarizers were adhered so that the
10 polarizing light transmittance axes became parallel each other. By contraries to the case when the dielectric anisotropy was positive, the curves of the threshold characteristics in FIG. 11 indicates a trend to be steep with decreasing the angle ϕ_{LC} . Therefore, in order to perform
15 a medium gray scale display with a sufficient voltage margin, ϕ_{LC} must be increased. However, when the ϕ_{LC} became equal to or larger than 45 degrees, the brightness indicated a trend to decrease. The optimum value for the angle ϕ_{LC} varies depending on the number of the medium gray
20 scales to be displayed, the required value for the brightness, the driven voltage, and whether any voltage is applied to the common electrode or not, as same as the case when the dielectric anisotropy is positive. A designer can control the threshold characteristics in a wide range by
25 selecting a suitable angle ϕ_{LC} . In consideration of the brightness, selection of an angle ϕ_{LC} equal to or less than 45 degrees is desirable.

The results obtained in the measurement of viewing angle characteristics on the respective cases, wherein the viewing angle were varied in a direction horizontally or vertically as same as the embodiment 1, indicated that no significant difference existed mutually and the display characteristics hardly changed. Particularly, no reversal of levels in a medium gray scale display (8 steps) was observed in a range within 50 degrees both horizontally and vertically. The orientation of the liquid crystal was preferable, and no orientation failure domain was generated. A low power consumption less than 10 W was realized.

(Embodiments 24-26)

In accordance with the present embodiments, the direction of the longitudinal axis of the liquid crystal molecule and the arrangement of the polarizers were set as same as the embodiment 21 ($\phi_{LC1} = \phi_{LC2} = \phi_{P1} = 15^\circ$, $\phi_{P2} = -75^\circ$), which had indicated the most favorable characteristics among the previous embodiments 20-23. And, only the product, $d \cdot \Delta n$, of the thickness d of the liquid crystal composition layer and the refractive index anisotropy Δn was varied. In the embodiments 24, 25, and 26, the thicknesses d of the liquid crystal composition layers were set as 4.0, 4.9, and 7.2 μm , respectively, and the $d \cdot \Delta n$ were set as 0.1748, 0.2141, and 0.3146 μm , respectively. In the above variation, the refractive index anisotropy Δn was taken as a constant number and only the thickness d of the

liquid crystal composition layer was varied. However, even if the refractive index anisotropy Δn is varied as same as the other liquid crystal display method (for instance, 90 degrees twisted nematic display method), the result on the optimum value for the brightness can be obtained.

Furthermore, even if the dielectric anisotropy of the liquid crystal composition layer is selected to be positive, the same result can be obtained. The observed results including the result of the embodiment 21 are indicated in FIGs. 12 (a) and 12 (b). FIG. 12 (a) indicates the results by taking the applied voltage as the abscissa, and FIG. 12 (b) indicates the results shown in FIG. 12 (a) by taking the $d \cdot \Delta n$ at a constant applied voltage, 7 Volts, as the abscissa. It is apparent from FIG. 12 (b) that the brightness strongly depends on and an optimum value of the $d \cdot \Delta n$ exists. In order to increase the brightness to at least 30 %, which is necessary in practical use, the $d \cdot \Delta n$ must be in a range from 0.21 to 0.36 μm . Furthermore, in order to increase the brightness to at least 50 %, the $d \cdot \Delta n$ must be in a range from 0.23 to 0.33 μm . In consideration of productivity such as a time for enclosing the liquid crystal and controlling the thickness of the liquid crystal composition layer etc., the value of the d is set at least 5.0 μm , and the $d \cdot \Delta n$ is desirably set as equal to or less than 0.08 μm as same as the present embodiment.

The liquid crystal display apparatus of the present

embodiment did not generate any deterioration of the image quality, and a wide viewing angle as same as the embodiment 1 and a low power consumption less than 10 W were realized. (Embodiments 27-29)

5 As the results of the embodiments 24-26 revealed, the optimum value of the $d \cdot \Delta n$ exists in a range from 0.21 to 0.36 μm , desirably a range from 0.23 to 0.33 μm . In consideration that the thickness of the liquid crystal composition layer having preferable productivity is at least 5.0 μm , the value of the refractive index anisotropy, Δn , must be equal to or less than 0.072, desirably equal to or less than 0.066. However, kinds of liquid crystal compounds having such a extremely low Δn are very restricted, and it is very difficult to be compatible with other characteristics required for practical use.

15 Therefore, a novel method has been invented, wherein the $d \cdot \Delta n$ of the liquid crystal composition layer is set higher somewhat than the optimum value, the excess amount of the $d \cdot \Delta n$ from the optimum value is compensated by inserting an optically anisotropic medium having a lower phase difference R_f than the $d \cdot \Delta n$ of the liquid crystal composition layer so as to cancel the phase difference generated by the liquid crystal composition layer, and an effective phase difference, which is obtained by joining

20 the liquid crystal composition layer and the optically anisotropic medium, is set at an optimum value in a range

25

from 0.21 to 0.36 μm .

The embodiments 27-29 were composed as same as the embodiment 3 except the following conditions;

5 The thickness of the liquid crystal composition layer was set respectively as 5.0, 5.2, and 5.5 μm . The value of the $d \cdot \Delta n$ was respectively 0.360, 0.3744, and 0.396 μm , because a nematic liquid crystal composition having a refractive index anisotropy of 0.072 (589 nm, 20 °C) was
10 used. Because the $d \cdot \Delta n$ was higher than the optimum range of 0.21 to 0.36 μm for preferable brightness and hue without any modification, coloration with an orange color was performed. An optically anisotropic medium composed of an unidirectional drawn film made of polyvinyl alcohol was
15 coated to the liquid crystal cell so as to compensate the birefringence phase difference of the liquid crystal when the liquid crystal cell was driven with a low voltage. That is, ϕ_R was set at 85 degrees as same as ϕ_{LC1} ($= \phi_{LC2}$). The phase difference R_f was respectively set as 0.07, 0.08, and
20 0.10 μm , and the value of $(d \cdot \Delta n - R_f)$ was respectively set as 0.29, 0.3044, and 0.296 μm so as to be in a range of 0.21 to 0.36 μm for preferable brightness and hue.

As the results, a wide viewing angle, no deterioration in image quality, and a low power consumption less than 10
25 W were realized as same as the other embodiments.

(Embodiment 30)

The liquid crystal composition layer in the embodiment

27 was replaced with a nematic liquid crystal composition (made by Merck, Co., ZLI-4518) having a negative dielectric anisotropy $\Delta\epsilon$ of -2.5, and Δn was 0.0712 (589 nm, 20 °C). Other composition was as same as the embodiment 21 except
 5 the following conditions;

The thickness of the liquid crystal composition layer was 5.5 μm , that is, the $d \cdot \Delta n$ was 0.3916 μm . An optically anisotropic medium composed of an unidirectional drawn film made of polyvinyl alcohol having the phase difference R_z was
 10 coated to the liquid crystal cell so as to make the value of $(d \cdot \Delta n - R_z)$ as 0.2816 μm , which was in a range of 0.21 to 0.36 μm for preferable brightness and hue.

As the results, a wide viewing angle, no deterioration in image quality, and a low power consumption less than 10
 15 W were realized as same as the other embodiments.

(Embodiment 31)

The composition of the present embodiment is as same as the embodiment 15 except the following conditions;

The Δn of the liquid crystal composition layer was
 20 0.072, and the gap d was 7.0 μm . Therefore, the $d \cdot \Delta n$ was 0.504 μm . The ϕ_{LC1} was 89.5 degrees, the orientation directions of the liquid crystal molecules at the upper and the lower boundaries were intercrossing with a right angle, and $|\phi_{LC1} - \phi_{LC2}|$ was set as 90 degrees. The polarizers were
 25 arranged so as to intercross each other with a right angle ($|\phi_{P2} - \phi_{P1}| = 90^\circ$), and a relationship with the liquid

crystal orientation direction was set to be optically rotatory mode, that is $\phi_{LC1} = \phi_{P1}$. As the result, a positive contrast display was obtained.

The measurement of electro-optical characteristics on the present embodiment reveals that the present embodiment realized a wide viewing angle, no deterioration of image quality, and a low power consumption as same as the other embodiments except a point, wherein the threshold voltages V_{10} , V_{90} became approximately twice in comparison with the other embodiments having a birefringence mode. The orientation of the liquid crystal was preferable, and no orientation failure domain was generated.

(Embodiments 32, 33)

The compositions of the present embodiments were as same as the embodiment 1 except the following condition;

The polarizers were arranged so as to obtain a dark state under a condition wherein the electric field was not nil, but was slightly applied. That is, the value of $|\phi_{LC1} - \phi_{P1}|$ was set as 5 degrees and 15 degrees, respectively, in the embodiments 32 and 33. The value of $|\phi_{P2} - \phi_{P1}|$ was set as 90 degrees.

As same as the other embodiments, preferable display characteristics in both viewing angle and image quality, and a low power consumption were obtained. The orientation of the liquid crystal was preferable, and no orientation failure domain was generated.

(Embodiments 34, 35)

The compositions of the present embodiments were as same as the embodiment 1 except the following condition;

The polarizers were arranged so as to obtain a dark state under a condition wherein the electric field was not nil, but was slightly applied. That is, the value of $|\phi_{LC1} - \phi_{P1}|$ was set as 5 degrees and 7 degrees, respectively, in the embodiments 34 and 35. The value of $|\phi_{P2} - \phi_{P1}|$ was set as 90 degrees. The thickness d of the liquid crystal composition layer was $6.3 \mu\text{m}$. Therefore, the $d \cdot \Delta n$ was $0.275 \mu\text{m}$.

The result of the electro-optical characteristics measurement on the present embodiments are shown in FIG.

13. In the case of the embodiment 34, the voltage V_{OFF} for getting a dark state was 3.0 Volts, and the voltage V_{ON} for a brightest state was 9.2 Volts. Therefore, when the liquid crystal display apparatus was driven with the voltage between the above V_{OFF} and V_{ON} , sufficiently high contrast could be obtained. Similarly, in the case of the embodiment 35, V_{OFF} was 5.0 Volts and V_{ON} was 9.0 Volts.

When the present embodiments were driven with the voltage between the above V_{OFF} and V_{ON} , preferable display characteristics in both viewing angle and image quality, and a low power consumption were obtained as same as the other embodiments. The orientation of the liquid crystal was preferable, and no orientation failure domain was generated.

(Embodiment 36)

An image signal was supplied to the signal wiring electrode; and concurrently, an alternate current waveform of 3.0 Volts was supplied to the common electrode. As the result, lowering of voltage supplied to the signal wiring
 5 electrode (8.3 V $\rightarrow$ 6.2 V) was realized.

Then, the present embodiment was driven with the voltage between the above V_{OFF} and V_{ON} . The orientation of the liquid crystal was preferable, and no orientation failure domain was generated as same as the other
 10 embodiments.

(Embodiment 37)

The composition of the present embodiment was as same as the embodiment 1 except the following condition;

The polarizers were arranged so as to obtain a dark
 15 state under a condition wherein the electric field was not nil, but was slightly applied. That is, the value of $|\phi_{LC1} - \phi_{P1}|$ was set as 45 degrees, and the value of $|\phi_{P2} - \phi_{P1}|$ was set as 90 degrees. In accordance with the above setting, the bright state was obtained by applying a low voltage and
 20 the dark state was obtained by applying a high voltage. Voltage dependence of brightness was measured and the result was shown by a solid line in FIG. 14.

As same as the other embodiments, preferable display characteristics in both viewing angle and image quality,
 25 and a low power consumption as less than 10 W were obtained. The contrast ratio was 35. The orientation of the liquid crystal was preferable, and no orientation failure

domain was generated.

(Embodiment 38)

A birefringence medium (unidirectional drawn polyvinyl
5 alcohol film) for compensating the residual phase
difference at the boundaries was inserted between the two
polarizers in the same composition with the embodiment 37.
The drawing direction ϕ_R of the film was set as -45 degrees
for intersecting the polarizer transmitting axis with a right
10 angle. The phase difference R_r was 15 nm.

As shown by a dotted line in FIG. 14, leakage of light
at applying a high voltage could be suppressed in
comparison with the embodiment 37, and the contrast ratio
was further improved to 150.

15 In accordance with the present invention, a thin film
transistor type liquid crystal display apparatus having a
wide viewing angle, a high contrast ration, a large
transmittance of the liquid crystal panel, and a low power
consumption can be obtained.



What is claimed is;

1. A liquid crystal display apparatus comprising:
 - a pair of substrates,
 - 5 a plurality of signal wiring electrodes and scanning wiring electrodes formed on said substrates, and
 - a liquid crystal composition layer interposed between said pair of substrates, wherein
 - said plurality of signal wiring electrodes and
 - 10 scanning wiring electrodes form a plurality of pixels by intersecting each other in a matrix state,
 - active elements for switching on-off pixel electrodes in said pixels are formed in said pixels,
 - an electric field is applied between said pixel
 - 15 electrode and a reference electrode in approximately parallel to a plane of the substrate when said active element is turned on,
 - a scanning wiring electrode driving circuit for supplying scan signals including at least two values of
 - 20 non-selected voltages is connected to said scanning wiring electrode, and
 - a signal wiring electrode driving circuit for supplying image signals is connected to said signal wiring electrode.
- 25
2. A liquid crystal display apparatus comprising:
 - a pair of substrates,



a plurality of signal wiring electrodes and scanning wiring electrodes formed on said substrates,

polarizing means arranged so as to hold said pair of substrates between, and

5 a liquid crystal composition layer interposed between said pair of substrates, wherein

said plurality of signal wiring electrodes and scanning wiring electrodes form a plurality of pixels by intersecting each other in a matrix state,

10 active elements for switching on-off pixel electrodes in said pixels are formed in said pixels,

an electric field is applied between said pixel electrode and a reference electrode in approximately parallel to a plane of the substrate when said active
15 element is turned on,

said liquid crystal composition layer and polarizing means are arranged so that a contrast ratio in a direction perpendicular to said substrate becomes at least 10, and a brightness transmittance becomes at least 15 %,

20 said pixel electrode and said reference electrode extend in the pixel to a first direction in approximately parallel to said signal wiring electrode,

a scanning wiring electrode driving circuit for supplying scan signals including at least two values of
25 non-selected voltages is connected to said scanning wiring electrode, and

a signal wiring electrode driving circuit for



supplying image signals is connected to said signal wiring electrode.

3. A liquid crystal display apparatus as claimed in claim
5 1, wherein

said reference electrode is a common electrode having a common potential to the plural pixels.

4. A liquid crystal display apparatus as claimed in claim
10 1 or claim 2, wherein

the non-selected voltage of the scan signals applied to said scanning wiring electrode changes with same cycles and same phases in all rows of the matrix, and synchronizing to which,

- 15 a voltage waveform, which changes with same cycles and same phases each other, is applied to a common electrode during all over the operating period and to the pixel electrode during the non-selected period.

- 20 5. A liquid crystal display apparatus as claimed in claim 4, wherein

the non-selected voltage of the scan signals which is applied to said scanning wiring electrode, and the voltage which is applied to a common electrode during all over the
25 operating period and to the pixel electrode during the non-selected period have approximately a same amplitude.



6. A liquid crystal display apparatus as claimed in any one of claims 1-5, wherein

a gap D between said pixel electrode and adjacent said reference electrode in a pixel of said pixels is larger than
5 1/3 of any of widths, W_p and W_c , of said pixel electrode and said reference electrode.

7. A liquid crystal display apparatus as claimed in any one of claims 1-5, wherein

10 all of said pixel electrode, said signal wiring electrode, said reference electrode, and said scanning wiring electrode are arranged on a same substrate of said pair of substrates.

15 8. A liquid crystal display apparatus as claimed in any one of claims 1-5, wherein

said reference electrode is arranged on a substrate, which is countered to another substrate whereon said active element is arranged, to form an auxiliary capacitance
20 element between said pixel electrode by interposing an insulator.

9. A liquid crystal display apparatus as claimed in any one of claims 1-6, wherein

25 said pixel electrode and said reference electrode are arranged on a same layer, and an auxiliary capacitance element is formed between said pixel electrode and said



scan wiring by interposing an insulator.

10. A liquid crystal display apparatus as claimed in any one of claims 1-6, wherein

5 respective of said pixel electrode and said reference electrode is arranged on each different one of two layers which are separated by interposing an insulator, a part of said pixel electrode and a part of said reference electrode are overlapped with interposing an insulator between the
10 electrodes, and an auxiliary capacitance element is formed at the overlapping portion.

11. A liquid crystal display apparatus as claimed in any one of claims 8-10, wherein

15 a vertical scanning period of driving signals supplied from said scanning wiring electrode driving circuit is set as shorter than a time constant which is defined as a product of a specific resistance and a dielectric constant of the insulating material composing said capacitance
20 element.

12. A liquid crystal display apparatus as claimed in any one of claims 8-10, wherein

 said reference electrode has a structure capable of
25 being used concurrently by adjacent pixels.

13. A liquid crystal display apparatus as claimed in any



one of claims 8-10, wherein

said reference electrode has a structure capable of being used concurrently by adjacent pixels, and

a part of common wiring is intersected with signal wiring with a right angle.

14. A liquid crystal display apparatus as claimed in claim 10, wherein

said pixel electrode or said reference electrode has a plane shaped in any one of a ring, a cruciform, a T-letter shape, a II shape, an I-letter shape, and a ladder shape.

15. A liquid crystal display apparatus as claimed in claim 10, wherein

said reference electrode is composed of a metallic electrode of which surface is coated with a self oxidized film or a self nitrized film.

16. A liquid crystal display apparatus as claimed in any one of claims 1 to 15, wherein

at least two kinds of color filters of different colors each other are provided on the one of said pair of substrates, and

a boundary of said color filters is overlapped with any one of said signal wiring electrode or said reference electrode.

17. A liquid crystal display apparatus as claimed in any one of claims 1 - 16, wherein

at least two kinds of color filters of different colors are provided on the one of said pair of substrates,

an organic polymer for flattening surface is laminated on said color filters,

said organic polymer is transparent, and

said transparent polymer film is used as an orientation film for controlling an orientation direction of



liquid crystal molecules on a boundary with the liquid crystal composition layer by processing said transparent polymer with a surface treatment or making the layer have anisotropy.

5

18. A liquid crystal display apparatus as claimed in claim 17, wherein

said organic polymer is composed of at least two kinds of materials,

10

the one of said organic polymer which is contacted with the liquid crystal has a function to control the orientation of the liquid crystal molecules in a designated direction, and

15

another one of said organic polymer which is adjacent to the color filters has a function to flatten the surface.

19. A liquid crystal display apparatus as claimed in claim 17 or claim 18, wherein

20

said organic polymer composed of at least a layer is an organic insulating layer which is contacted directly with said active element.

20. A liquid crystal display apparatus as claimed in claim 19, wherein

25

said organic polymer is an organic insulating layer which is contacted directly with said active element and said liquid crystal composition layer, and



said organic insulating layer has both functions as a protecting film for said active element, and a orientation controlling film for the liquid crystal molecules.

5

21. A liquid crystal display apparatus as claimed in any one of claims 1-20, wherein

the dielectric anisotropy of said liquid crystal composition layer is positive, and

10 an angle $|\phi_{LC}|$, which is formed by the orientation direction of the liquid crystal molecules on a boundary of at least one of the substrates with the electric field, is in a range at least 45 degrees and less than 90 degrees.

15 22. A liquid crystal display apparatus as claimed in claim 21, wherein

said angle $|\phi_{LC}|$ is in a range at least 60 degrees and equal to or less than 88 degrees.

20 23. A liquid crystal display apparatus as claimed in any one of claims 1-18, wherein

the dielectric anisotropy of said liquid crystal composition layer is negative, and

25 an angle $|\phi_{LC}|$, which is formed by the orientation direction of the liquid crystal molecules on a boundary of at least one of the substrates with the electric field, is in a range more than zero degrees and less than 45 degrees.



24. A liquid crystal display apparatus as claimed in claim 23, wherein

said angle $|\phi_{LC}|$ is in a range at least 2 degrees and equal to or less than 30 degrees.

5

25. A liquid crystal display apparatus as claimed in any one of claims 21-24, wherein,

relating to the orientation in said liquid crystal composition layer, an angle ϕ_{LC1} of the orientation direction of the liquid crystal molecules on the boundary of the one of substrates and an angle ϕ_{LC2} of the orientation direction of the liquid crystal molecules on the boundary of another substrates are in approximately parallel each other ($\phi_{LC1} \approx \phi_{LC2}$), and

15 a product, $d \cdot \Delta n$, of the thickness d and the refractive index anisotropy Δn of said liquid crystal composition layer is in a range between $0.21 \mu m$ and $0.38 \mu m$.

20 26. A liquid crystal display apparatus as claimed in claim 25, wherein

an optical anisotropic medium having a phase difference R_f which is lower than said product, $d \cdot \Delta n$, of the thickness d and the refractive index anisotropy Δn of said liquid crystal composition layer is inserted so as to

25 compensate the phase difference generated by said liquid crystal composition layer, and the difference of their absolute values, $|d \cdot \Delta n| - |R_f|$, is set in a range between



0.21 μm and 0.38 μm .

27. A liquid crystal display apparatus as claimed in any one of claims 21-24, wherein,

5 relating to the orientation in said liquid crystal composition layer, an angle ϕ_{LC1} of the orientation direction of the liquid crystal molecules on the boundary of the one of substrates and an angle ϕ_{LC2} of the orientation direction of the liquid crystal molecules on the boundary of another
10 substrates are intercrossed each other,

an angle, $|\phi_{LC1} - \phi_{LC2}|$, which is formed by said intercrossing, is at least 80 degrees and equal to or less than 100 degrees, and

a product, $d \cdot \Delta n$, of the thickness d and the refractive
15 index anisotropy Δn of said liquid crystal composition layer is in a range between 0.40 μm and 0.60 μm .

28. A liquid crystal display apparatus as claimed in any one of claims 17-27, wherein,

20 a declining angle of the liquid crystal molecules is equal to or less than 4 degrees on at least either one of the boundaries.

29. A liquid crystal display apparatus as claimed in claim
25 22, wherein

the dielectric anisotropy of said liquid crystal composition layer is positive,



said polarizing means is a pair of polarizers holding said liquid crystal composition layer between, and

an angle, ϕ_{LC} , which is formed by a longitudinal direction of the liquid crystal molecules on at least one of said boundaries with the electric field, is approximately equal to an angle, ϕ_p , of a transmittance axis (or an absorbing axis) of a polarizer of said pair of polarizers.

30. A liquid crystal display apparatus as claimed in claim 21 or claim 22, wherein

the dielectric anisotropy of said liquid crystal composition layer is positive,

said polarizing means is a pair of polarizers holding said liquid crystal composition layer between,

an angle, ϕ_{LC} , which is formed by a longitudinal direction of the liquid crystal molecules on at least one of said boundaries with the electric field, has a same sign with an angle, ϕ_p , of a transmittance axis (or an absorbing axis) of a polarizer of said pair of polarizers,

the absolute value of the angle, ϕ_{LC} , is larger than the absolute value of the angle, ϕ_p , and

the difference, $|\phi_{LC} - \phi_p|$, is in a range at least 3 degrees and equal to or less than 15 degrees.

31. A liquid crystal display apparatus as claimed in claim 24, wherein



the dielectric anisotropy of said liquid crystal composition layer is negative,

said polarizing means is a pair of polarizers holding said liquid crystal composition layer between,

5 an angle, ϕ_{LC} , which is formed by a longitudinal direction of the liquid crystal molecules on at least one of said boundaries with the electric field, has a same sign with an angle, ϕ_p , of a transmittance axis (or an absorbing axis) of a polarizer of said pair of polarizers, and

10 the absolute value of the angle, ϕ_{LC} , is approximately equal to the absolute value of the angle, ϕ_p .

32. A liquid crystal display apparatus as claimed in claim 24, wherein

15 the dielectric anisotropy of said liquid crystal composition layer is negative,

said polarizing means is a pair of polarizers holding said liquid crystal composition layer between,

an angle, ϕ_{LC} , which is formed by a longitudinal
20 direction of the liquid crystal molecules on at least one of said boundaries with the electric field, is smaller than an angle, ϕ_p , of a transmittance axis or an absorbing axis of a polarizer of said pair of polarizers, and

the difference, $|\phi_{LC} - \phi_p|$, is in a range at least 3
25 degrees and equal to or less than 15 degrees.

33. A liquid crystal display apparatus as claimed in any



one of claims 29-32, wherein,

an image signal is applied to said pixel electrode,
and a voltage signal waveform is applied to said reference
electrode so as to raise a voltage which is applied to said
5 liquid crystal composition layer.

34. A liquid crystal display apparatus as claimed in claim
26, wherein

said polarizing means is a pair of polarizers holding
10 said liquid crystal composition layer between, which are
arranged at positions to form a bright state by applying a
low voltage V_L and a dark state by applying a high voltage
 V_H , and

a transparent medium, which compensates a residual
15 phase difference at boundaries of the liquid crystal layer
at applying the high voltage V_H , is inserted between said
pair of polarizers.