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**Baek**

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(54) **TRANSFLECTIVE LIQUID CRYSTAL DISPLAY DEVICE WITH DUAL LIQUID CRYSTAL LAYER THICKNESS AND PARTICULAR HALF WAVE PLATE ANGLE**

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( * ) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

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(30) **Foreign Application Priority Data**

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(51) **Int. Cl.**[7] ..... **G02F 1/1335**
(52) **U.S. Cl.** ..... **349/117**; 349/113; 349/141
(58) **Field of Search** ..... 349/76, 117, 119, 349/121, 114

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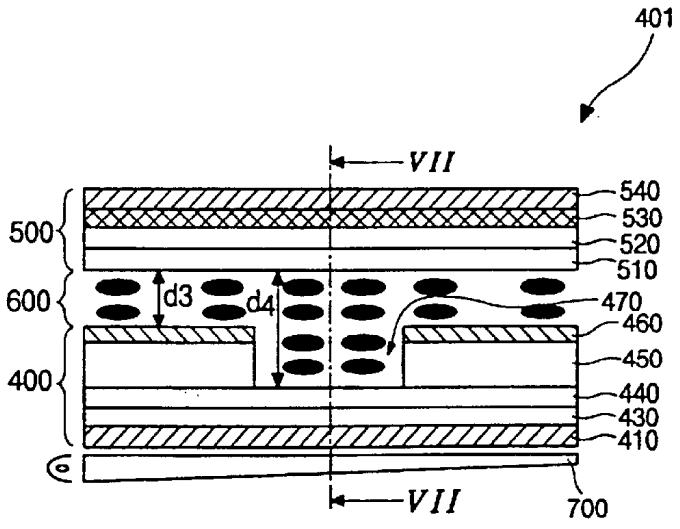
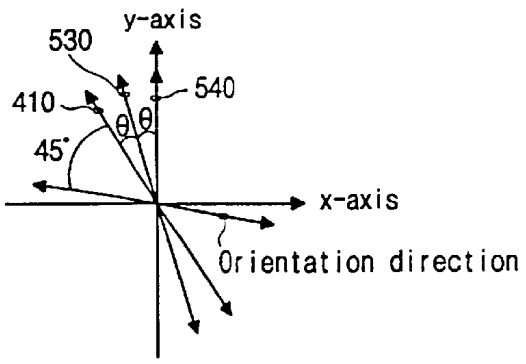
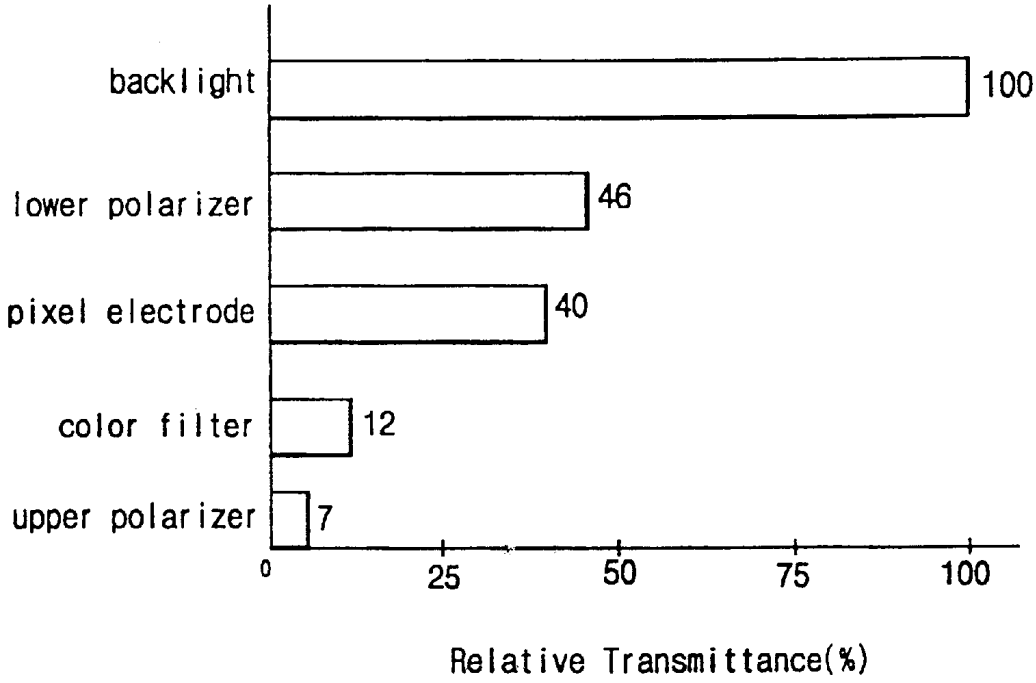
(57) **ABSTRACT**

A transflective LCD device improves a light transmittance in both the transmissive mode and the reflective mode and improves efficiency in the use of the light regardless of wavelength. To properly control the ON/OFF-switch of the blue wavelength band or the red wavelength band, the transflective LCD device adopts a half wave plate ($\lambda/2$) and changes the optic axes of the polarizers and the retardation film.

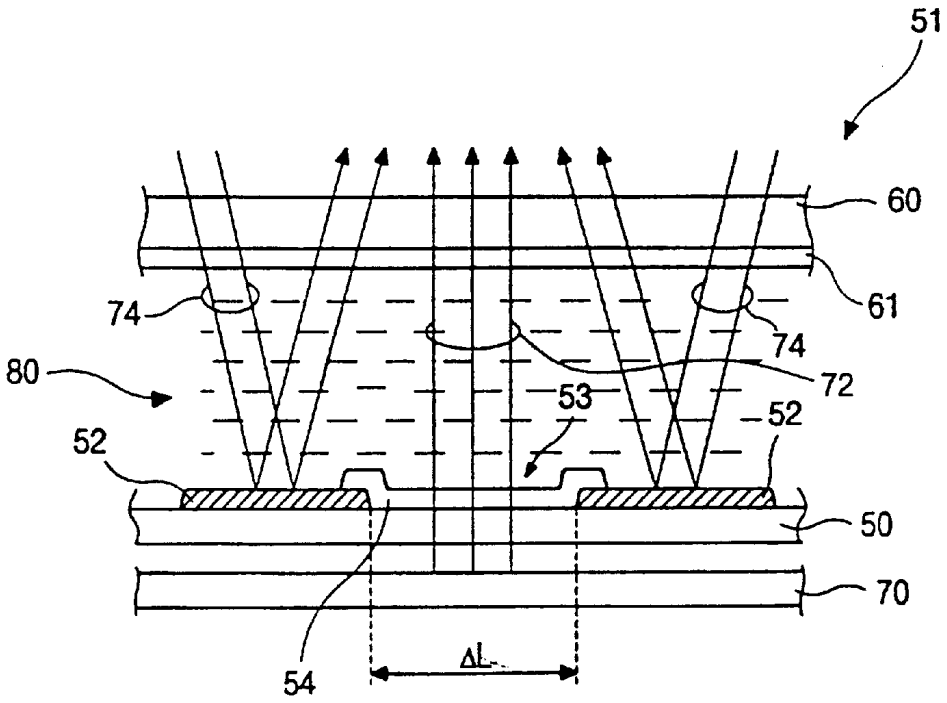
**14 Claims, 8 Drawing Sheets**



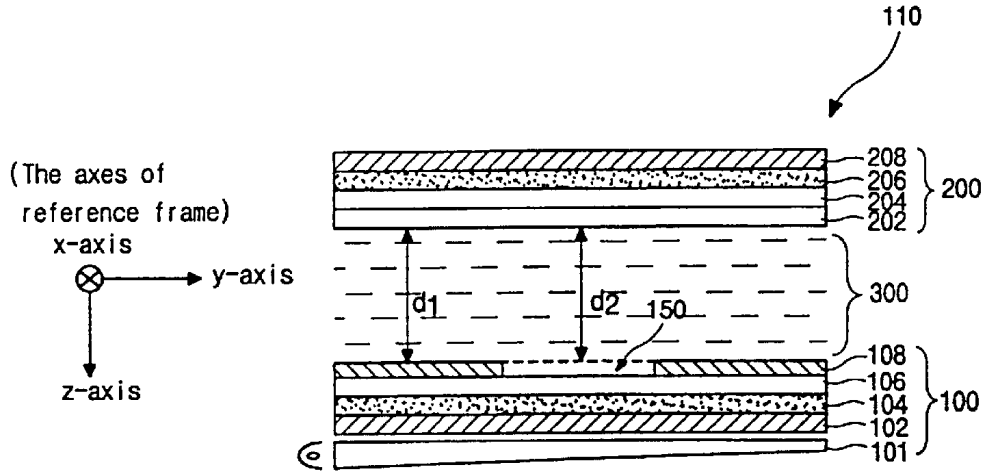





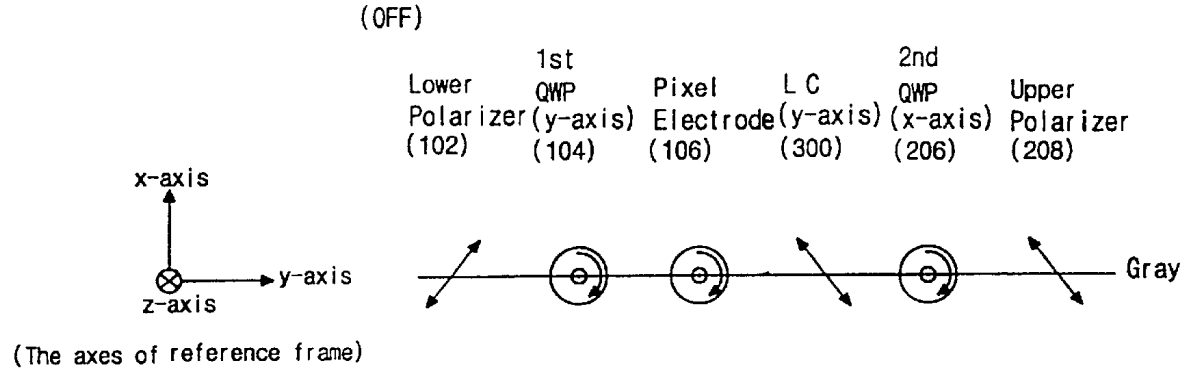

(RELATED ART)
FIG. 1



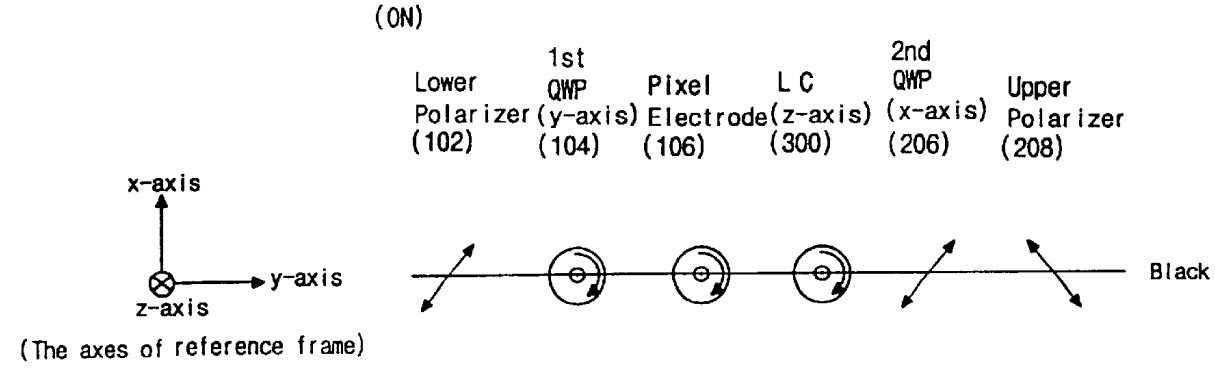

(RELATED ART)
FIG. 2



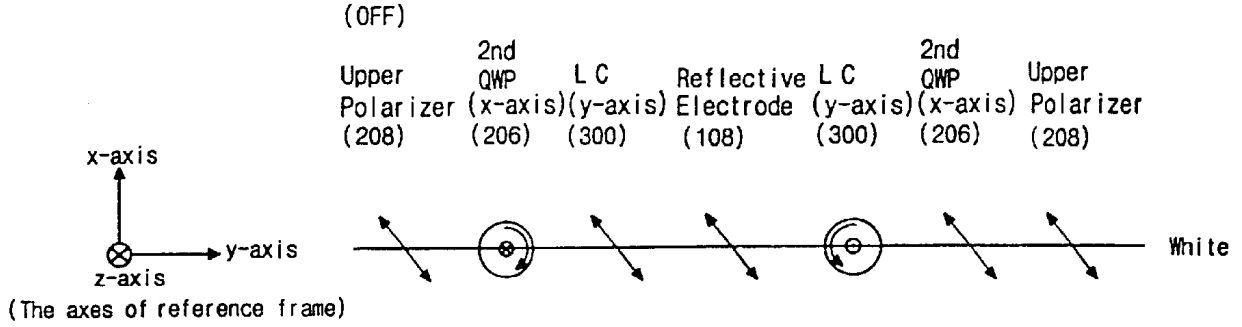

(RELATED ART)
FIG. 3



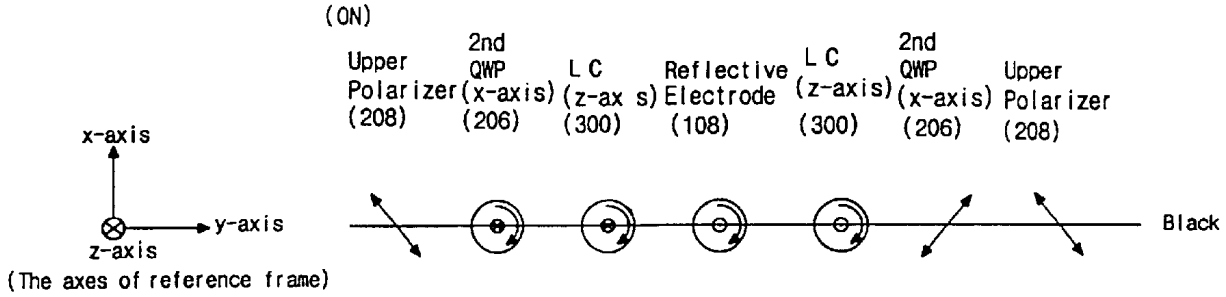

(RELATED ART)
FIG. 4A




(RELATED ART)
FIG. 4B




(RELATED ART)
FIG.5A




(RELATED ART)
FIG.5B

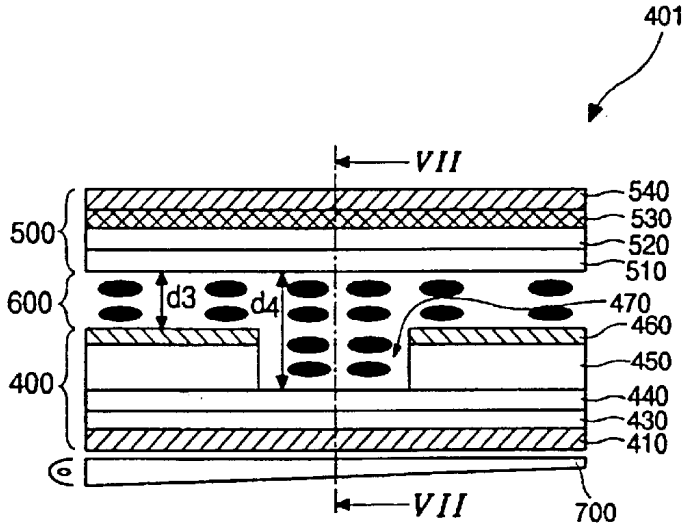



FIG. 6

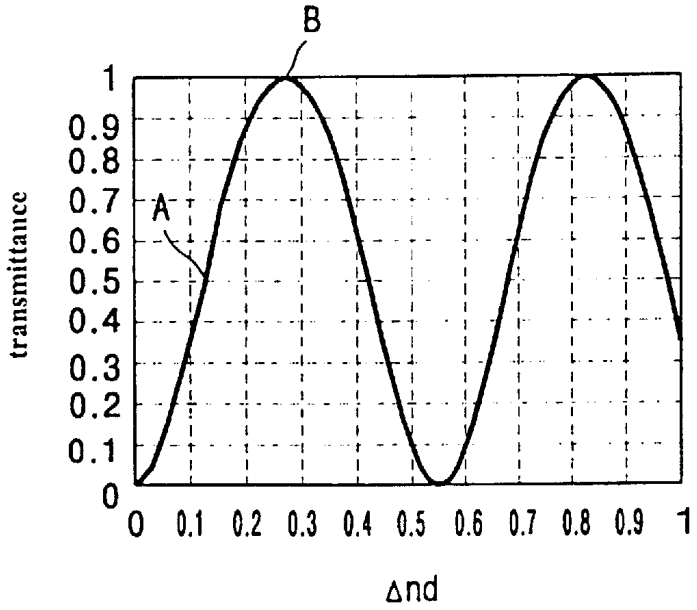

B
A
transmittance
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1
Δnd

FIG.7

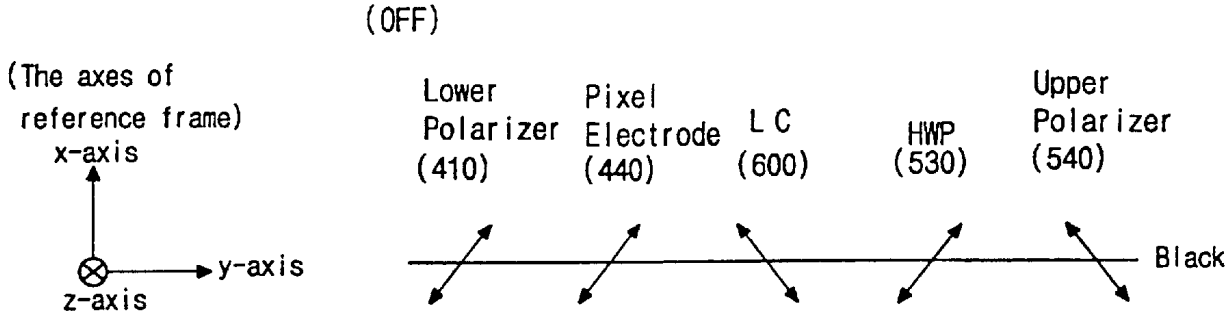

(OFF)
(The axes of reference frame)
x-axis
y-axis
z-axis
Lower Polarizer (410)
Pixel Electrode (440)
L C (600)
HWP (530)
Upper Polarizer (540)
Black

FIG.8A

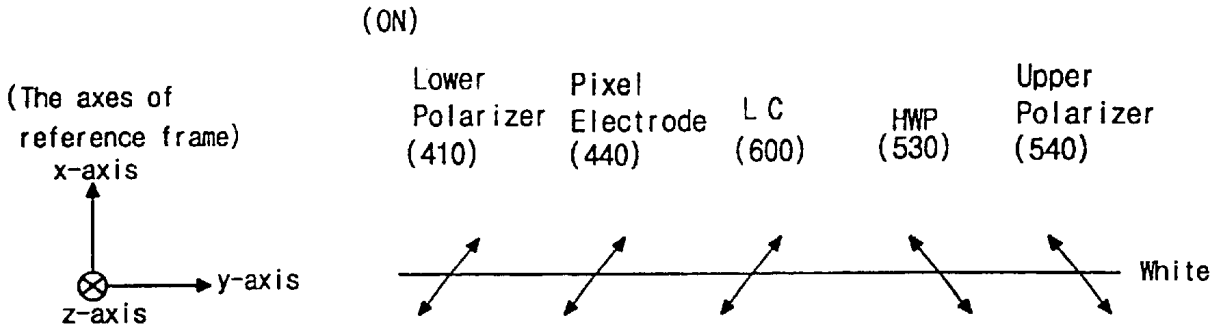



FIG.8B

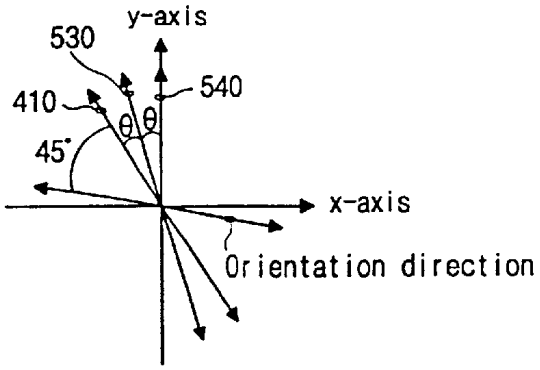



FIG.9A

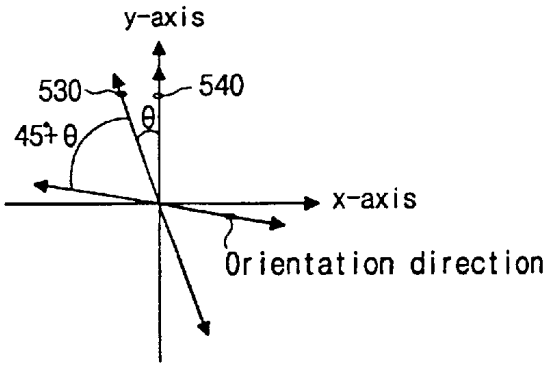



FIG.9B

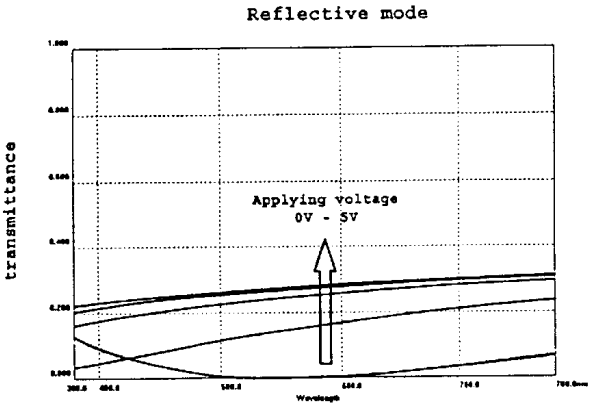



FIG.10A

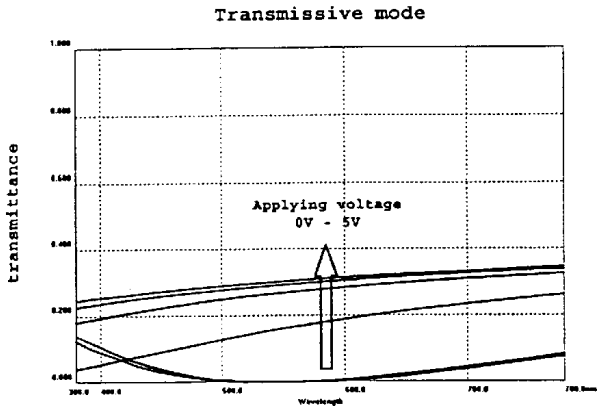



FIG. 10B

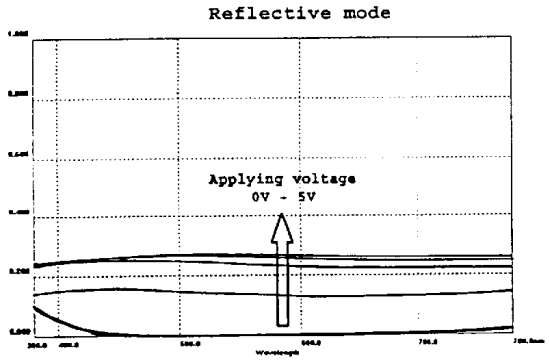



FIG.11A

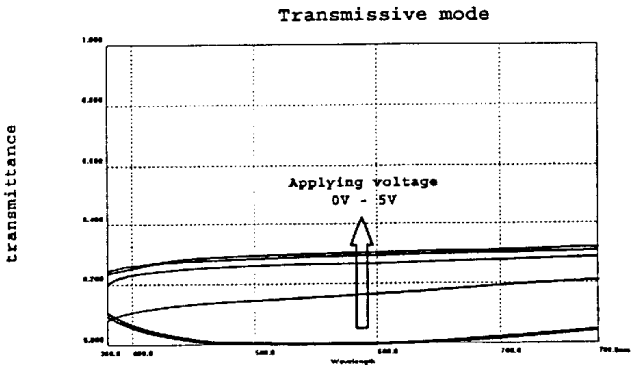



FIG.11B

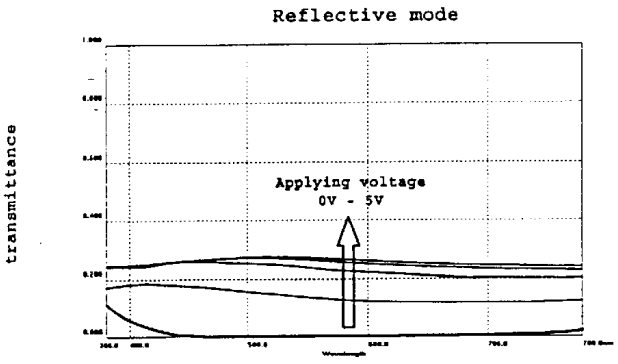



FIG.12A

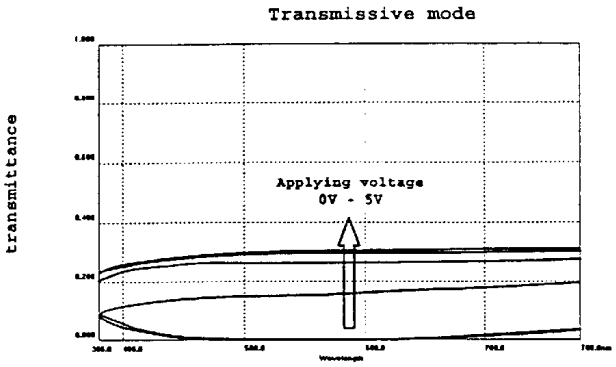



FIG.12B

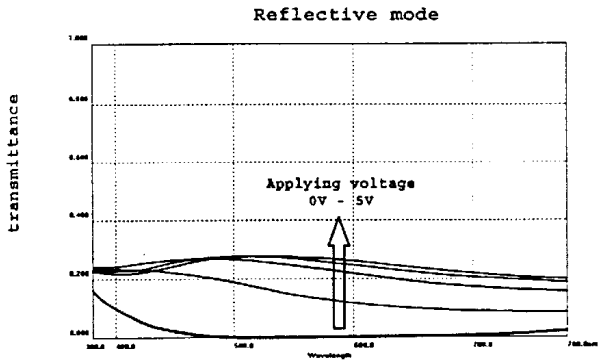



FIG.13A

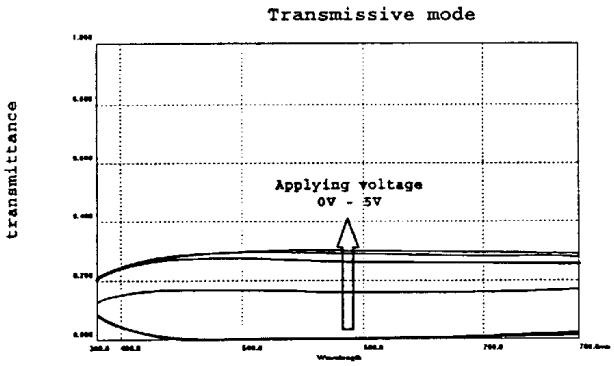



FIG.13B

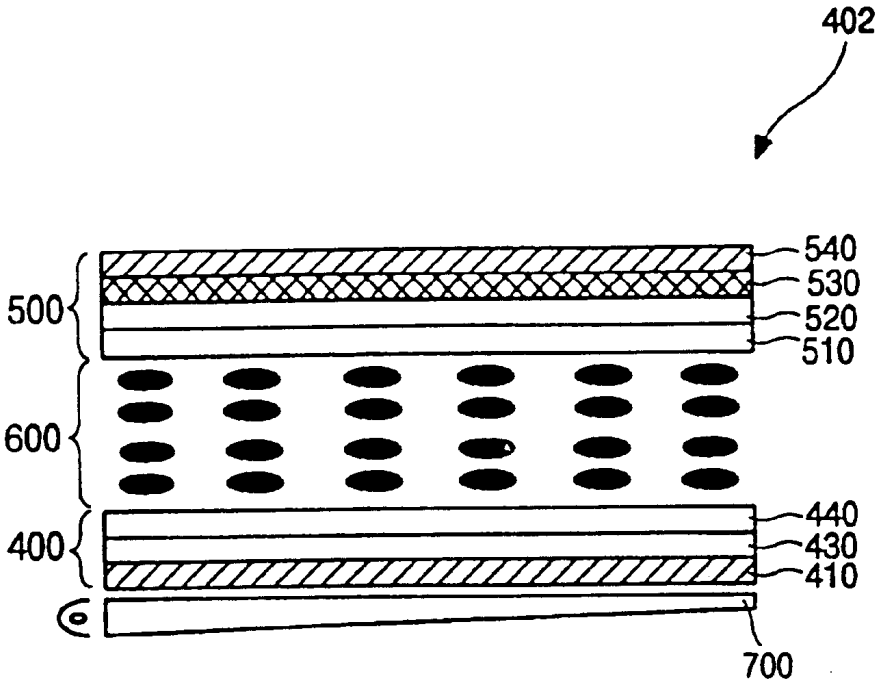

402
540
530
520
510
500
600
440
430
410
400
700

FIG. 14

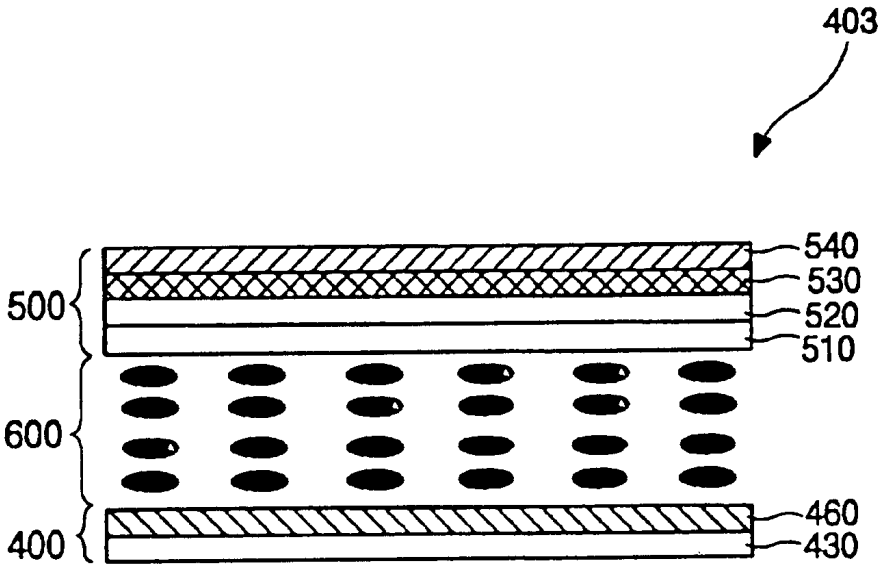

403
540
530
520
510
500
600
460
430
400

FIG. 15

# TRANSFLECTIVE LIQUID CRYSTAL DISPLAY DEVICE WITH DUAL LIQUID CRYSTAL LAYER THICKNESS AND PARTICULAR HALF WAVE PLATE ANGLE

This application claims the benefit of Korean Patent Application No. 2000-20117, filed on Apr. 17, 2000, under 35 U.S.C. §119, the entirety of which is hereby incorporated by reference.

## BACKGROUND OF THE INVENTION

1. Field of the invention

The present invention relates to a liquid crystal display (LCD) device, and more particularly, to a transflective LCD device that has a high brightness.

2. Description of Related Art

Until now, the cathode-ray tube (CRT) has been developed for and is used mainly for the display systems. However, the flat panel display is beginning to make its appearance due to the requirements of small depth dimensions, undesirably low weight and low voltage power supply. At present, the thin film transistor-liquid crystal display (TFT-LCD) with high resolution and small depth dimension has been developed.

During operation of the TFT-LCD, when the pixel is turned ON by the corresponding switching elements, the pixel transmits light generated from a backlight device. The switching elements are generally amorphous silicon thin film transistors (a-Si:H TFTs) which use an amorphous silicon layer. Advantageously, the amorphous silicon TFTs can be formed on low cost glass substrates using low temperature processing.

In general, the TFT-LCD transmits an image using light from the backlight device that is positioned under the TFT-LCD panel. However, the TFT-LCD only employs 3~8% of the incident light generated from the backlight device, i.e., the inefficient optical modulation.

Referring to FIGS. **1**–**5**B, a TFT-LCD device that is manufactured by a conventional method will now be explained in some detail.

FIG. **1** is a graph illustrating a light transmittance respectively measured after light passes through each layer of a conventional liquid crystal display device. The two polarizers have a transmittance of 45% and, the two substrates have a transmittance of 94%. The TFT array and the pixel electrode have a transmittance of 65%, and the color filter has a transmittance of 27%. Therefore, the typical transmissive TFT-LCD device has a transmittance of about 7.4% as seen in FIG. **1**, which shows a transmittance after light passes through each layer of the device. For this reason, the transmissive TFT-LCD device requires a high, initial brightness, thereby increasing electric power consumption of the backlight device. A relatively heavy battery is needed to supply a sufficient power to the backlight of such a device. Moreover, there still exists a problem that the battery cannot be used for a long time.

In order to overcome these problems, a reflective TFT-LCD has been developed. Since the reflective TFT-LCD device uses ambient light, it is light and easy to carry. Also, the reflective TFT-LCD device is superior in aperture ratio as compared to a transmissive TFT-LCD device. Namely, since the reflective TFT-LCD substitutes an opaque reflective electrode for a transparent electrode material in the pixel of the conventional transmissive TFT-LCD, it reflects the ambient light.



As described above, since the reflective TFT-LCD device uses ambient light other than an internal light source such as a backlight device, battery life can be increased resulting in longer use times. In other words, the reflective TFT-LCD device is driven using light reflected from the reflective electrode. Thus, only the drive circuitry that drives the liquid crystal uses the battery power in the reflective TFT-LCD device.

Additionally, the reflective TFT-LCD device has a problem that it is affected by its surroundings. For example, the brightness of indoors-ambient light differs largely from that of outdoors-ambient light. Also, even in the same location, the brightness of ambient light depends on the time of day (e.g., noon or dusk). Therefore, the reflective TFT-LCD device cannot be used at night without ambient light.

Accordingly, there is a need for a transflective TFT-LCD device that can be used during daytime hours as well as nighttime because the transflective LCD device can be changed to either a transmissive mode or a reflective mode depending on the desired condition of operation.

FIG. **2** is a schematic cross-sectional view illustrating one pixel of the transflective TFT-LCD device according to the conventional art. As shown, the transflective TFT-LCD device **51** includes a liquid crystal panel and a backlight device **70**. The liquid crystal display panel includes lower and upper substrates **50** and **60** and an interposed liquid crystal layer **80**. The upper and lower substrates **60** and **50** are called a color filter substrate and an array substrate, respectively.

The upper substrate **60** has color filters **61**. The lower substrate **50** serves as the array substrate and includes TFTs (not shown), and transmissive and reflective electrodes **54** and **52** serve as a pixel electrode. The reflective electrode **52** surrounds the transmissive electrode **54** or has a light transmitting hole **53** having a dimension "ΔL". The reflective electrode **52** includes a conductive material such as chrome (Cr), aluminum (Al) or tantalum (Ta), which has a high optical reflectivity, and therefor reflects the ambient light **74**. The transmissive electrode **54**, formed in the light transmitting hole **53**, transmits the light **72** emitted from the backlight device **70**.

The transflective LCD device **51** is operated as follows. First, in the reflective mode, the incident light **74** from the outside is reflected from the reflective electrode **52** and is directed toward the upper substrate **60**. At this time, when the electrical signals are applied to the reflective electrode **52** by the switching elements (not shown), the arrangement of the liquid crystal layer **80** varies, and thus, the reflected light of the incident light **74** is colored by the color filter **61** and is displayed as colored light. Second, in the transmissive mode, light **72** emitted from the backlight device **70** passes through the transmissive electrode **54** (or transmitting hole **53**). At this time, when the electrical signals are applied to the transmissive electrode **54** by the switching elements (not shown), arrangement of the liquid crystal layer **80** varies. Thus, the light **72** passing through the liquid crystal layer **80** is colored by the color filter **61** and displayed in the form of images with other colored lights.

FIG. **3** is a cross-sectional view of the conventional transflective LCD device. In FIG. **3**, the color filter is not depicted because it does not affect the polarization state of the light. As shown, the conventional transflective LCD device **110** includes a first substrate **106** (an array substrate) and a second substrate **204** (a color filter substrate). A liquid crystal layer **300** that affects the polarization state of the light according to the applied voltages is interposed between the first substrate **106** and the second substrate **204**.

On the surface of the first substrate **106** that faces the second substrate **204**, a TFT (not shown), a transparent conductive electrode **150** (i.e., a pixel electrode) and a reflective electrode **108** (i.e., a pixel electrode) are disposed. Lower polarizer **102** is disposed on the other surface of the first substrate **106**. Moreover, a lower retardation film (quarter wave plate; QWP) **104** having a phase difference $\lambda/4$ is positioned between the first substrate **106** and the lower polarizer **102**. A backlight device **101** is adjacent to the lower polarizer **102**. The lower polarizer **102**, the lower retardation film **104**, the first substrate **106**, the transparent conductive electrode **150**, and the reflective electrode **108** are all together referred to as a lower substrate **100**.

On one surface of the second substrate **204** is a second retardation film, i.e., Quarter Wave Plate ($\lambda/4$ plate); referred to hereinafter as a second QWP **206**. On the second QWP **206** is an upper linear polarizer **208**. A transparent conductive common electrode **202** is on the other surface of the second substrate **204** facing the lower substrate **100**. The common electrode **202**, the second substrate **204**, the second QWP **206**, and the upper polarizer **208** are all together referred to as an upper substrate **200**.

The second QWP **206** changes the state of the light. Namely, the second QWP **206** converts the linearly polarized light into the right- or left-handed circularly polarized light, and it also converts the right- or left-handed circularly polarized light into the linearly polarized light of which polarization direction is 45° or 135°.

The polarization state of the light of the conventional transflective LCD device described above will be explained hereinafter in accordance with each layer. FIGS. **4**A and **4**B illustrate the state of the light from the backlight device **101** through selected components of the conventional transflective LCD device **110** of FIG. **3** when in the transmissive mode. The conventional transflective LCD device has a normally white (NW) mode, i.e., the transflective LCD device displays a white color when a signal voltage is not applied.

FIG. **4**A shows the state of the light from the backlight device in the transmissive mode when a signal voltage is not applied, i.e., when the TFT is turned OFF. The light from the backlight device enters the lower polarizer **102**. In this case, transmissive axis of the lower polarizer is arranged perpendicular to that of the upper polarizer **208**. Only the portion of the light that is parallel with the transmissive axis of the lower polarizer **102** passes through the lower polarizer **102** as linearly polarized light of which polarization direction is 45°. The resultant linearly polarized light is converted into left-handed circularly polarized light as it passes through the first QWP **104**. Then, the left-handed circularly polarized light passes through the first substrate **106** and through the transparent conductive electrode **150** without any phase shift. Next, the left-handed circularly polarized light is converted into linearly polarized light of which polarization direction is 45° as it passes through the liquid crystal layer **300**, this being due to a optical retardation $\lambda/4$ of the liquid crystal layer **300**. The linearly polarized light then passes through the transparent conductive common electrode **202** and through the second substrate **204**. As the linearly polarized light passes through the second QWP **206**, the linearly polarized light is converted into left-handed circularly polarized light. Only the portion of the left-handed circularly polarized light that is parallel with the transmissive axis of the upper polarizer **208** passes through the upper polarizer **208**. That is, about 50% of the left-handed circularly polarized light can pass through the upper polarizer **208**. As a result, the LCD device produces a dark gray color.

FIG. **4**B shows the state of the light from the backlight device in the transmissive mode when a signal voltage is applied, i.e., the TFT is turned ON. The liquid crystal does not affect the incident light, and thus the incident light passes through the liquid crystal layer without any change of polarization state. As depicted in FIG. **4**B, the light from the backlight device **101** enters the lower polarizer **102**. Only the linearly polarized light of the light of which polarization direction is 45° can pass through the lower polarizer **102**. The resultant linearly polarized light is converted into left-handed circularly polarized light as it passes through the first QWP **104**. Then, the left-handed circularly polarized light passes through the first substrate **106**, through the transparent conductive electrode **150**, and through the liquid crystal layer **300** without any polarization change. The left-handed circularly polarized light also passes through the common electrode **202** and through the second substrate **204** without any change of polarization state. The left-handed circularly polarized light is then converted into linearly polarized light by the second QWP **206**. The polarization direction of this linearly polarized light is 45°. Therefore, the linearly polarized light is polarized perpendicular to the transmissive axis of the upper polarizer **208** and does not pass through the upper linear polarizer **208**. Thus, the LCD device produces a black color.

FIGS. **5**A and **5**B illustrate the polarization state of the ambient light through selected components of the conventional transflective LCD device **110** of FIG. **3** when in the reflective mode.

FIG. **5**A shows the state of the ambient light in the reflective mode when a signal voltage is not applied, i.e., the TFT is turned OFF. The ambient light illuminates the upper linear polarizer **208**. Only the portion of the ambient light that is parallel with the transmissive axis of the upper polarizer **208** passes through the upper polarizer **208** as linearly polarized light (135° from x-axis of reference frame). The linearly polarized light is changed into right-handed circularly polarized light by the second QWP **206** which is parallel with x-axis of the reference frame. The left-handed circularly polarized light passes through the second substrate **204** and through the common electrode **202** without any polarization change. The right-handed circularly polarized light then passes through the liquid crystal layer **300** that has optical retardation (defined by $(d \cdot \Delta n)$ hereinafter) $\lambda/4$ which is parallel with y-axis of reference frame. The right-handed circularly polarized light is then converted into linearly polarized light of which polarization direction is 135° as it passes through the liquid crystal layer **300**. The linearly polarized light is then reflected by the reflective electrode **108**. The reflected linearly polarized light is converted back into a right-handed circularly polarized light as it passes through the liquid crystal layer **300**. The right-handed circularly polarized light is then converted into a linearly polarized light of which polarization direction is 135° as it passes through the second QWP **206**. The linearly polarized light is parallel to the transmissive axis of the upper polarizer **208**, and thus passes through the upper linear polarizer **208**. Thus, the LCD device produces light having a white color.

FIG. **5**B shows the state of the ambient light in the reflective mode when a signal voltage is applied, i.e., the TFT is turned ON. In the ON-state, the liquid crystal layer **300** does not affect polarization state of the incident light. Thus, incident light passes through the liquid crystal layer without any change of polarization state.

Accordingly, the ambient light that passes through the upper polarizer **208** as linearly polarized light is converted

into right-handed circularly polarized light by the second QWP **206**. The right-handed circularly polarized light passes through the second substrate **204**, through the common electrode **202**, and through the liquid crystal layer **300**. The right-handed circularly polarized light is then reflected by the reflective electrode **108**, which causes the right-handed circularly polarized light to become converted into left-handed circularly polarized light with a phase shift of 180° via a mirror effect. The left-handed circularly polarized light then passes through the liquid crystal layer **300**, through the common electrode **202**, and through the second substrate **204**. The left-handed circularly polarized light is then converted into linearly polarized light of having a polarization direction of 45° as it passes through the second QWP **206**. The linearly polarized light is perpendicular to the transmissive axis of the upper polarizer **208**, and as such does not pass through the upper linear polarizer **208**. Thus, the LCD device results in a black color.

As described above, the conventional transflective TFT-LCD device has both the reflective mode and the transmissive mode such that it can be used in anywhere and anytime of the day. However, referring to FIG. **4**A, the LCD device produces the dark gray color, unlike the FIG. **5**A, although it should display a white color when the signal voltage is not applied. This is because about 50% of right-handed circularly light having passed through the second QWP **206** only can pass through the upper polarizer **208**.

Therefore, since the difference of the brightness occurs between in the reflective mode and in the transmissive mode when the TFT is turned OFF, the definition and picture quality of the transflective LCD device are lowered. Accordingly, the transflective LCD device is designed more focusing on the reflective mode and cell gaps "$d_1$" (see FIG. **3**) of the reflective portion and "$d_2$" (see FIG. **3**) of the transmitting portion are substantially equal. Namely, the ambient light in the reflective mode passes through the liquid crystal layer twice due to reflection of the reflective electrode, while the light from the backlight device in the transmissive mode passes through the liquid crystal layer just once. Thus, the transflective LCD device cannot produce the pure white color when the signal voltage is not applied.

Moreover, the design of the conventional transflective LCD device focuses on the way that the length of cell gap and the optic axes of other components depend on the central wavelength band of the visible light (the green wavelength band, i.e., 550 nm). Therefore, the conventional LCD device does not properly control the ON/OFF-switch of the blue wavelength band or the red wavelength band. Furthermore, both lower and upper substrates are required in the conventional LCD device.

In other words, the transmissive axis of the lower polarizer is perpendicular to that of the upper polarizer in the conventional LCD device. Moreover, if the cell gap of the LCD device is designed focusing on the green wavelength band (centered at 550 nm), the LCD device precisely transmits or shut off the green wavelength band. However, the LCD device does not transmits or shut off the other bands substantially. These limitations cause a decrease in the switching ability of the LCD device.

## SUMMARY OF THE INVENTION

Accordingly, the present invention is directed to a transflective LCD device that substantially overcomes one or more of the problems due to limitations and disadvantages of the related art.

To overcome the problems described above, the present invention provides reflective, transmissive and transflective LCD devices. The present invention increases the brightness and the efficiency in the use of light from a backlight device.

Additional features and advantages of the invention will be set forth in the description that follows, and in part will be apparent from the description, or may be learned by practice of the invention. The objectives and other advantages of the invention will be realized and attained by the structure particularly pointed out in the written description and claims hereof as well as the appended drawings.

In order to achieve the above object, a transflective liquid crystal display (LCD) device of the present invention includes first and second substrates facing and spaced apart from each other; a first polarizer formed under the first substrate; a retardation film and a second polarizer that are formed in series on the second substrate; a backlight device being adjacent to the first polarizer; a common electrode on a surface of the second substrate facing the first substrate; a pixel electrode formed on the first substrate and corresponding to each pixel, the pixel electrode is divided into a transmissive portion and a reflective portion; a liquid crystal layer interposed between the first and second substrates, wherein a thickness of the liquid crystal layer between the common electrode and the transmissive portion of the pixel electrode is more than 1.5 and less than 2.5 times larger than a thickness of the liquid crystal layer between the common electrode and the reflective portion of the pixel electrode; and a slow axis of the retardation film is disposed at an angle "θ" from a transmissive axis of the second polarizer; and a transmissive axis of the first polarizer is disposed at the angle "**2**θ" from the transmissive axis of the second polarizer.

To achieve the above object, an LCD device according to the present invention includes first and second substrates facing and spaced apart from each other; a first polarizer formed under the first substrate; a retardation film and a second polarizer that are formed in series on the second substrate; a backlight device being adjacent to the first polarizer; a liquid crystal layer interposed between the first and second substrates; a common electrode on a surface of the second substrate facing the first substrate, the common electrode is formed of transparent conductive material; and a pixel electrode formed on the first substrate and corresponding to each pixel, the pixel electrode is formed of transparent conductive material; wherein a slow axis of the retardation film is disposed at an angle "θ" from a transmissive axis of the second polarizer; and wherein a transmissive axis of the first polarizer is disposed at the angle "2θ" from the transmissive axis of the second polarizer.

To achieve the above object, an LCD device according to the present invention includes first and second substrates facing and spaced apart from each other; a retardation film and a polarizer that are formed in series on the second substrate; a liquid crystal layer interposed between the first and second substrates; a common electrode on a surface of the second substrate facing the first substrate, the common electrode is formed of a transparent conductive material; a pixel electrode formed on the first substrate and corresponding to each pixel, the pixel electrode is formed of a conductive material; and a slow axis of the retardation film is disposed at an angle "θ" from a transmissive axis of the polarizer.

## BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of the present invention and the advantages thereof, reference is now made to

the following descriptions taken in conjunction with the accompanying drawings, in which like reference numerals denote like parts, and in which:

FIG. **1** is a graph illustrating a relative transmittance respectively measured after light passes through each layers of a conventional liquid crystal display (LCD) device;

FIG. **2** is a cross-sectional view illustrating a typical transflective LCD device;

FIG. **3** is a cross-sectional view illustrating elements of the transflective LCD device according to the conventional art;

FIGS. **4**A and **4**B are views illustrating the state of light from a backlight device passing through components of the transflective LCD device of FIG. **3** when it is operating in a transmissive mode;

FIGS. **5**A and **5**B are views illustrating the state of ambient light passing through components of the transflective LCD device of FIG. **3** when it is operating in a reflective mode;

FIG. **6** is a cross-sectional view illustrating elements of the transflective LCD device according to a preferred embodiment of the present invention;

FIG. **7** is a graph illustrating the light transmittance of line VII—VII of FIG. **6** depending on the optical retardation ($d_4 \cdot \Delta n$), as it is calculated using the Jones Matrix formulation;

FIGS. **8**A and **8**B show the polarization state of the light from the backlight device in the transmissive mode depending of whether a signal voltage is applied or not;

FIGS. **9**A and **9**B show a positional relationship of the LCD device elements of FIG. **6** according to another embodiment;

FIGS. **10**A to **13**B are graphs illustrating a light transmittance of the transflective LCD device with respect to wavelengths of the light when applying the voltage to liquid crystal layer, and respectively show the transmittance with respect to the value of the angle "θ" of FIGS. **9**A and **9**B.

FIG. **14** is a cross-sectional view of a transmissive LCD device according to a preferred embodiment.

FIG. **15** is a cross-sectional view of a reflective LCD device according to a preferred embodiment.

## DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Reference will now be made in detail to the preferred embodiment of the present invention, example of which is illustrated in the accompanying drawings.

FIG. **6** is a cross-sectional view of a transflective LCD device according to an embodiment of the present invention. The color filters are not depicted in FIG. **6** because it does not affect the polarization state of the light. As shown, the transflective LCD device **401** is widely divided into a backlight device **700**, an array substrate **400**, a liquid crystal layer **600**, and a color filter substrate **500**. The liquid crystal layer **600** affecting polarization state of the light is interposed between the array substrate **400** and the color filter substrate **500**. The backlight device **700** is arranged under the lower substrate **400** and emits light into the liquid crystal layer **600**.

The array substrate **400** includes a lower transparent substrate **430**, a lower polarizer **410**, a transparent conductive electrode **440**, a passivation layer **450** and a reflective electrode **460** having a transmitting hole **470**. On the surface of the lower substrate **430**, which faces the upper substrate **500**, are disposed a TFT (not shown) and the transparent conductive electrode **440** (i.e., a pixel electrode). On the transparent conductive electrode **440** is the passivation layer **450** that has the transmitting hole **470**. On the passivation layer **450** is the reflective electrode **460** that has the transmitting hole **470**. Thus, the transmitting hole **470** penetrates the reflective electrode **460** (i.e., a pixel electrode) and passivation layer **450** to the transparent conductive electrode **440**. In this embodiment, the transparent conductive electrode **440** and the reflective electrode **460** act together as a pixel electrode. On the other surface of the first substrate **430** is the lower polarizer **410**.

The color filter substrate **500** includes a transparent common electrode **510**, an upper transparent substrate **520**, a half wave plate (HWP; $\lambda/2$) **530** and an upper polarizer **540**. On one surface of the upper transparent substrate **520** is the HWP **530**. On the HWP **530** is the upper linear polarizer **540**. The common electrode **510** is formed on the other surface of the second substrate **520** facing the array substrate **400**. Also, the HWP **530** acts as a retarder and causes phase difference of $\lambda/2$. The passivation layer **450** is formed in order to make different cell gaps between the pixel electrode (**440** and **460**) and the common electrode **510**. Namely, a first cell gap "$d_3$" is defined in the interval between the reflective electrode **460** and the common electrode **510**, i.e., a reflective portion. Moreover, a second cell gap "$d_4$" is defined in the interval between the transparent electrode **440** and the transparent common electrode **510**, i.e., a transmitting portion. As shown, the passivation layer **450** of the array substrate **400** is formed in order to make a difference between the cell gaps "$d_3$" and "$d_4$". Thus, the thickness of the liquid crystal layer **600**, i.e., the cell gaps, is different. Preferably, the second cell gap "$d_4$" is twice as long as the first cell gap "$d_3$" (i.e., $d_4=2d_3$). Although an alignment film is not depicted in FIG. **6**, it can be formed between the liquid crystal layer **600** and the common and pixel electrodes.

FIG. **7** is a graph illustrating the light transmittance along line VII—VII of FIG. **6** depending on the optical retardation ($d_4 \cdot \Delta n$), as it is calculated using the Jones Matrix formulation. If the first cell gap "$\Delta n \cdot d_3$" is designed to be $\lambda/4$ ($\lambda$=550 nm), the second cell gap "$d_4$" is equal to the first cell gap "$d_3$" ($d_4=d_3$) in a portion "A" while the second cell gap "$d_4$" is twice as large as the first cell gap "$d_3$" ($d_4=2d_3$) in a portion "B". Namely, as shown in FIG. **7**, the transmittance is theoretically 100% in the portion "B" in which the thickness of the second cell gap "$d_4$" is twice as large as that of the first cell gap "$d_3$".

Referring back to FIG. **4**A, the light after passing through the second QWP **206** is the left-handed circularly polarized light in the transmissive mode of the conventional transflective LCD device. Thus, about 50% of the right-handed circularly polarized light that is parallel with the transmissive axis of the upper polarizer **208** can pass through the upper polarizer **208**.

However, according to the principles of the present invention, the light passing through the retardation film (HWP) **530** (see FIG. **6**) is converted into linearly polarized light. Referring to FIG. **6**, the liquid crystal layer **600** acts like the quarter wave plate, which has a phase difference of $\lambda/4$, in an OFF-state in the reflective portion. As a result, if the second cell gap "$d_4$" is twice as large as the first cell gap "$d_3$", the liquid crystal layer **600** has a phase difference of $\lambda/2$ in the transmitting portion when the TFT is turned OFF. For more a detailed explanation, the relation between the cell gap and the optical retardation of the liquid crystal layer can be calculated by the following equations.

$$\Delta n \cdot d_3 = \lambda/4 \text{ (in the reflective mode)} \quad (1)$$

$$\because d_4 = 2\, d_3$$

$$\Delta n \cdot d_4 = \lambda/2 \text{ (in the transmissive mode)} \quad (2)$$

FIG. **8**A shows the polarization state of the light from the backlight device in the transmissive mode when a signal voltage is not applied, i.e., the TFT is turned OFF. The light from the backlight device enters the lower polarizer **410**. Only the portion of the light that is parallel with the transmissive axis of the lower polarizer **410** passes through the lower polarizer **410** as linearly polarized light of which polarization direction is 45° from x-axis of reference frame. The resultant linearly polarized light passes through the lower transparent substrate **430** and through the transparent conductive electrode **440** (i.e., the pixel electrode). Then, the linearly polarized light is converted into another linearly polarized light having polarization direction of 135° from the x-axis of the reference frame as it passes through the liquid crystal layer **600**. This results from the liquid crystal layer **600** having the optical retardation λ/2. The linearly polarized light then passes through the transparent common electrode **510** and through the upper transparent substrate **520**. As the linearly polarized light passes through the HWP **530** that has the optical retardation λ/2, the linearly polarized light having polarization direction of 135° from the x-axis of the reference frame is converted into linearly polarized light of which polarization direction is 45° from x-axis of reference frame. This linearly polarized light is polarized perpendicular to the transmissive axis of the upper polarizer **540**, and therefore, does not pass through the upper linear polarizer **540**. Thus, the LCD device produces a black color. Namely, the transflective LCD device according to the principles of the present invention has a normally black (NB) mode, i.e., the transflective LCD device displays a black color when a signal voltage is not applied.

FIG. **8**B shows the polarization state of the light from the backlight device in the transmissive mode when a signal voltage is applied, i.e., the TFT is turned ON. The light from the backlight device enters the lower polarizer **410**. Only the portion of the light that is parallel with the transmissive axis of the lower polarizer **410** passes through the lower polarizer **410** as linearly polarized light of which polarization direction is 45° from x-axis of reference frame. The resultant linearly polarized light passes through the lower transparent substrate **430**, through the transparent conductive electrode **440** (i.e., the pixel electrode), and through the transmitting hole **470**. When the linearly polarized light passes through the liquid crystal layer **600**, it is not converted and polarized any more because the liquid crystal layer **600** ideally does not have the optical retardation in the ON-state. The linearly polarized light having polarization direction of 45° then passes through the transparent common electrode **510** and through the upper transparent substrate **520**. As the linearly polarized light passes through the HWP **530** that has the optical retardation of λ/2, the linearly polarized light having polarization direction of 45° from the x-axis of the reference frame is converted into linearly polarized light of which polarization direction is 135° from x-axis of reference frame. The linearly polarized light is polarized parallel with the transmissive axis of the upper polarizer **540**, and thus passes through the upper linear polarizer **540**. Thus, the LCD device produces a white color.

Although the reflective mode is not depicted in the drawings, the LCD device is completely dark when the TFT is turned OFF, and absolutely bright when the TFT is turned ON.

As mentioned before, the optical retardation of the HWP is λ/2 (λ=550 nm), the optical retardation of the liquid crystal layer is λ/2 (λ=550 nm) in the transmissive mode, and the optical retardation of the liquid crystal layer is λ/4 (λ=550 nm) in the reflective mode. However, these optical retardations are ideal values. Namely, when fabricating the LCD device in practice, these optical retardations vary within the scope of the way that does not largely affect the optical effect and efficiency of the LCD device. For example, referring back to FIG. **7**, the optical retardation of the liquid crystal layer in the transmissive mode is not precisely λ/2 (at λ=550 nm), i.e., 275 nm. Namely, when the optical retardation ranges from 250 nm to 300 nm, the decrease of the transmittance is less than 3% of the maximum value. This decreased transmittance is an allowable value in practice. In view of aforementioned example, the optical retardation of the liquid crystal layer in the reflective mode ranges from 110 nm to 160 nm instead of the precise optical retardation of λ/4 (at λ=550 nm), i.e., 137.5 nm. From these examples, the optical retardation of the HWP ranges from 250 nm to 300 nm.

The embodiment described above is just one exemplary and explanatory in the case of a homogeneous alignment layer LCD device. However, if an LCD device included homeotropic alignment layers, the homeotropic alignment layer LCD device produces the opposite results from the above-mentioned homogeneous alignment layer LCD device. Namely, even though the homeotropic alignment layer LCD device has the aforementioned structure and configuration, the homeotropic alignment layer LCD device produces a white state when the TFT is turned OFF and the LCD device produces a black state when the TFT is turned ON. Moreover, a negative type liquid crystal that has a negative dielectric constant is required for the homeotropic alignment layer LCD device.

As described above, the present invention adopts the HWP instead of the pair of QWPs. In contrast, the conventional art uses two QWPs in the upper and lower substrates, respectively. However, the present invention only uses one HWP in the upper substrate. Thus, the structure of the present invention reduces the number of components in the LCD device, thereby decreasing manufacturing cost.

Another embodiment of the present invention will now be explained hereinafter. By re-arranging the optical directions of elements of the LCD device, the transflective LCD device can achieve high efficiency in switching broad-band wavelengths of the light.

FIGS. **9**A and **9**B show a positional relationship of the LCD device elements of FIG. **6** according to another embodiment. FIG. **9**A shows a positional relationship of the elements of FIG. **6** in the transmissive mode, and FIG. **9**B shows a positional relationship in the reflective mode.

Referring to FIG. **9**A, a transmissive axis of the upper polarizer **540** is parallel with the y-axis. The slow axis of the HWP **530** is disposed at an angle "θ" from that of the upper polarizer **540**. The transmissive axis of the lower polarizer **410** is disposed at the angle "2θ" from that of the upper polarizer **540**. The orientation direction of the liquid crystal, which determines the arrangement of the liquid crystal molecules, is 45° from the transmissive axis of the lower polarizer **410**.

FIG. **9**B shows a positional relationship of the axes of the LCD device elements in the reflective mode. As shown, the transmissive axis of the lower polarizer **410** is not depicted due to the fact that the lower polarizer **410** does not affect the state of the light in the reflective mode. The transmissive axis of the upper polarizer **540** is parallel with the y-axis and

the slow axis of the HWP **530** is disposed at the angle "θ" from that of the upper polarizer **540**. Thus, the orientation direction of the liquid crystal is "45°+θ" from the slow axis of the HWP **530**.

As aforementioned and referring to FIGS. **9**A and **9**B, the transmissive axis of the upper polarizer **540** is not perpendicular to that of the lower polarizer **410**. Namely, the angle "2θ" represents the angle between the transmissive axis of the upper polarizer and that of the lower polarizer.

FIGS. **10**A to **13**B are graphs illustrating a light transmittance of the transflective LCD device with respect to wavelengths of the light when applying the voltage to liquid crystal layer, and respectively show the transmittance with respect to the value of the angle "θ" of FIGS. **9**A and **9**B. Namely, the graphs show the switching ability of the transflective LCD device according to the angle "θ" that is given 0°, 10°, 12.5° and 17.5° while applying voltages.

Referring to FIGS. **10**A to **13**B, the angle "θ", which is the slow axis angle of the HWP, varies considerably from 0° to 17.5°. Each line in the graphs represents a gradient when the voltage is applied and varies from 0V to 5V. When the angle "θ" is 10°, i.e., the slow axis angle of the HWP as shown in FIGS. **11**A and **11**B, the transmissive axis angle of the lower polarizer **410** is 20° from the transmissive axis of the upper polarizer and the liquid crystal has the orientation direction 55° from the slow axis of the HWP. At this time, the switching ability of the transflective LCD device is most stable in the reflective mode. Namely, the switching ability to the broad-band wavelengths in the reflective mode tends to be stable when the angle "θ" increases from 0° to 10°. However, the switching ability to the broad-band wavelengths except the green wavelength band (centered at 550 nm) tends to decline when the angle "θ" increases from 12.5° to 17.5°, and thus the transmittance decreases.

In addition, in the transmissive mode, the switching ability to the blue wavelength band (centered at 430 nm) becomes increasing when the angle "θ" increases from 0° to 17.5°. The switching ability in the transmissive mode of the transflective LCD device is most stable when the angle "θ" is 17.5°.

As described above, the most stable and efficient value of the angle "θ" is different in both the reflective and transmissive modes of the transflective LCD device. However, for the purpose of satisfying both the reflective and transmissive mode, the angle "θ" is approximately about 12.5°. This re-arrangement of the optical directions of the LCD device elements is not exclusively used in the first embodiment. Namely, this re-arrangement can be used in a reflective LCD device or in a transmissive LCD device, respectively. If the transmissive LCD device adopts the re-arrangement described above, the angle "θ" is beneficially about 17.5°. If the reflective LCD device adopts this re-arrangement described above, the angle "θ" is approximately 10°.

FIG. **14** is a cross-sectional view of a transmissive LCD device according to a preferred embodiment. The color filters are not depicted in FIG. **14** because it does not affect the polarization state of the light. As shown, the transmissive LCD device **402** is widely divided into a backlight device **700**, an array substrate **400**, a liquid crystal layer **600**, and a color filter substrate **500**. The liquid crystal layer **600** is interposed between the array substrate **400** and the color filter substrate **500**. The backlight device **700** is arranged under the lower substrate **400** and emits light into the liquid crystal layer **600**.

The array substrate **400** includes a lower transparent substrate **430**, a lower polarizer **410** and a transparent conductive electrode **440**. On the surface of the lower substrate **430**, which faces the upper substrate **500**, are a TFT (not shown) and the transparent conductive electrode **440** as a pixel electrode. An alignment layer can be on the transparent conductive electrode **440**. On the other surface of the first substrate **430** is the lower polarizer **410**.

The color filter substrate **500** includes a transparent common electrode **510**, an upper transparent substrate **520**, a half wave plate (HWP; λ/2) **530** and an upper polarizer **540**. On one surface of the upper transparent substrate **520** is the HWP **530** as a retardation film. On the HWP **530** is the upper linear polarizer **540**. The common electrode **510** is formed on the other surface of the second substrate **520** facing the array substrate **400**. An alignment film can be formed on the common electrode **510**. The above-mentioned half wave film (HWP) **530** substitutes for the pair of retardation films of the conventional LCD device. Also, the HWP **530** acts as a retarder and causes phase difference of λ/2.

FIG. **15** is a cross-sectional view of a reflective LCD device according to a preferred embodiment. The color filters are not depicted in FIG. **15** because it does not affect the polarization state of the light. As shown, the reflective LCD device **403** is widely divided into an array substrate **400**, a liquid crystal layer **600**, and a color filter substrate **500**. The liquid crystal layer **600** is interposed between the array substrate **400** and the color filter substrate **500**.

The array substrate **400** includes a lower transparent substrate **430** and a reflective electrode **460**. On the surface of the lower substrate **430**, which faces the upper substrate **500**, are a TFT (not shown) and the reflective electrode **460** as a pixel electrode. An alignment layer can be formed on the reflective electrode **460** although not depicted.

The color filter substrate **500** includes a transparent common electrode **510**, an upper transparent substrate **520**, a half wave plate (HWP; λ/2) **530** and an upper polarizer **540**. On one surface of the upper transparent substrate **520** is the HWP **530**. On the HWP **530** is the upper linear polarizer **540**. The common electrode **510** is formed on the other surface of the second substrate **520** facing the array substrate **400**. The above-mentioned half wave film (HWP) **530** substitutes for the pair of retardation films of the conventional LCD device. And the HWP **530** acts as a retarder and causes phase difference of λ/2. Although not explicitly shown, an alignment layer can be formed on the common electrode **510**.

As depicted and mentioned hereinbefore, the efficiency in the use of the light from the backlight device is maximized in the transmissive mode when fabricating the transflective LCD device that is designed greater focusing in the reflective mode according to an embodiment of the present invention. Moreover, it is another advantage that the transflective LCD device according to an embodiment of the present invention can uniformly control the broad-band wavelengths of the visible ray.

While the invention has been particularly shown and described with reference to the preferred embodiments thereof, it will be understood by those skilled in the art that the foregoing and other changes in form and details may be made therein without departing from the spirit and scope of the invention.

What is claimed is:

**1**. A transflective liquid crystal display (LCD) device, comprising:

first and second substrates facing and spaced apart from each other;

a first polarizer formed under the first substrate;

a half wave plate and a second polarizer that are formed in series on the second substrate;

a backlight device being adjacent to the first polarizer;

a common electrode on a surface of the second substrate facing the first substrate;

a pixel electrode formed on the first substrate and corresponding to each pixel, the pixel electrode is divided into a transmissive portion and a reflective portion;

a liquid crystal layer interposed between the first and second substrates, wherein a thickness of the liquid crystal layer between the common electrode and the transmissive portion of the pixel electrode is more than 1.5 and less than 2.5 times larger than a thickness of the liquid crystal layer between the common electrode and the reflective portion of the pixel electrode; and, within a range of about 10 degrees to 17.5 degrees

wherein a slow axis of the half wave plate is disposed at an angle "θ" from a transmissive axis of the second polarizer; and

wherein a transmissive axis of the first polarizer is disposed at the angle "2θ" from the transmissive axis of the second polarizer.

**2**. The transflective LCD device according to claim **1**, further comprising alignment layers formed between the liquid crystal layer and the first and second substrates.

**3**. The transflective LCD device according to claim **1**, wherein the common electrode is transparent.

**4**. The transflective LCD device according to claim **1**, wherein molecules of the liquid crystal layer are arranged in a horizontal direction when a voltage is not applied to the common and pixel electrodes.

**5**. The transflective LCD device according to claim **4**, wherein an orientation direction of the liquid crystal layer is disposed at an angle "2θ+45°" from the transmissive axis of the second polarizer.

**6**. The transflective LCD device according to claim **4**, wherein an optical retardation of the liquid crystal layer between the common electrode and the transmissive portion of the pixel electrode ranges from 250 nm to 300 nm.

**7**. The transflective LCD device according to claim **4**, wherein an optical retardation of the liquid crystal layer between the common electrode and the reflective portion of the pixel electrode ranges from 110 nm to 160 nm.

**8**. The transflective LCD device according to claim **1**, wherein molecules of the liquid crystal layer are arranged in a vertical direction when a voltage is not applied to the common and pixel electrodes.

**9**. The transflective LCD device according to claim **8**, wherein the molecules of the liquid crystal layer are arranged in a horizontal direction when the voltage is applied to the common and pixel electrodes.

**10**. The transflective LCD device according to claim **8**, wherein an orientation direction of the liquid crystal layer is disposed at an angle "2θ+45°" from the transmissive axis of the second polarizer.

**11**. The transflective LCD device according to claim **8**, wherein an optical retardation of the liquid crystal layer between the common electrode and the transmissive portion of the pixel electrode ranges from 250 nm to 300 nm.

**12**. The transflective LCD device according to claim **8**, wherein an optical retardation of the liquid crystal layer between the common electrode and the reflective portion of the pixel electrode ranges from 110 nm to 160 nm.

**13**. The transflective LCD device according to claim **1**, wherein an optical retardation of the half wave plate ranges from 250 nm to 300 nm.

**14**. The transflective LCD device according to claim **1**, wherein the angle "θ" ranges from 10° to 15°.

* * * * *

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|---|---|---|---|
| 专利名称(译) | 具有双液晶层厚度和特定半波片角度的半透半反液晶显示装置 | | |
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| [标]申请(专利权)人(译) | BAEK HEUM IL | | |
| 申请(专利权)人(译) | BAEK HEUM-IL | | |
| 当前申请(专利权)人(译) | LG.飞利浦液晶CO.，LTD. | | |
| [标]发明人 | BAEK HEUM II | | |
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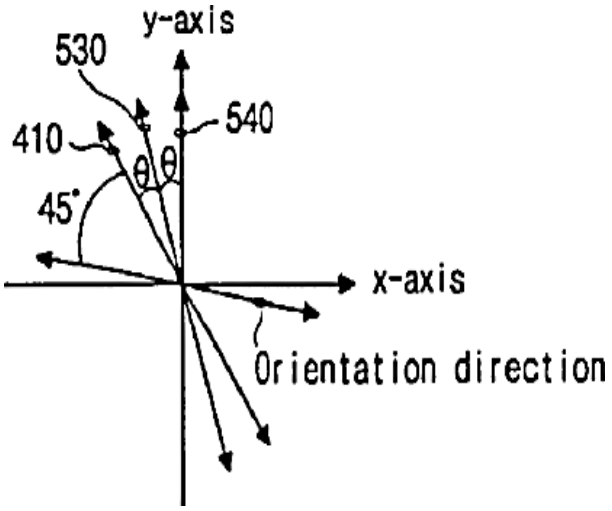
透射反射型LCD装置在透射模式和反射模式下都提高了透光率，并且无论波长如何都提高了光的使用效率。为了适当地控制蓝色波长带或红色波长带的ON / OFF开关，透射反射型LCD装置采用半波片（λ/ 2）并改变偏振器和延迟膜的光轴。