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(54) **LIQUID CRYSTAL DISPLAY DEVICE COMPRISING A SHADING CONDUCTIVE LAYER FORMED AT LEAST NEAR AN OPENING OR CUT OF AN ELECTRODE**

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(52) **U.S. Cl.** ......................... **349/111**; 349/44; 349/114; 349/129; 349/130; 349/143

(58) **Field of Classification Search** ....................... None
See application file for complete search history.

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*Primary Examiner*—Andrew Schechter
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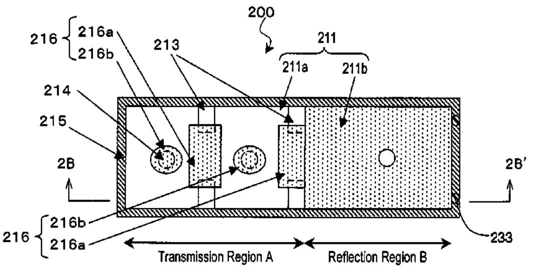
(74) *Attorney, Agent, or Firm*—Nixon & Vanderhye P.C.

(57) **ABSTRACT**

The liquid crystal display device of the invention has a plurality of pixels, each including a first electrode **111**, a second electrode **131** and a vertically aligned liquid crystal layer **120** interposed between the first and second electrodes. The first electrode has at least one opening **114** or cut **113** formed at a predetermined position in the pixel. At least one shading conductive layer **116** electrically connected to the first electrode is formed at least near the at least one opening or cut. In each of the plurality of pixels, a plurality of regions in which the directions of tilt of liquid crystal molecules are different from one another are formed when at least a predetermined voltage is applied across the liquid crystal layer.

**19 Claims, 13 Drawing Sheets**



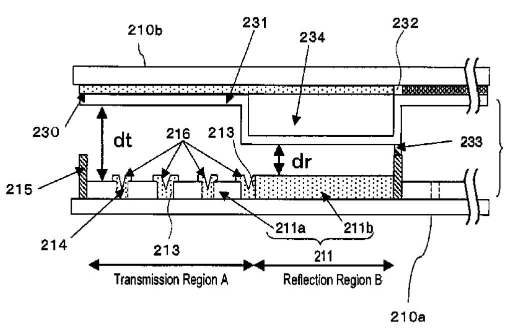



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FIG.1A

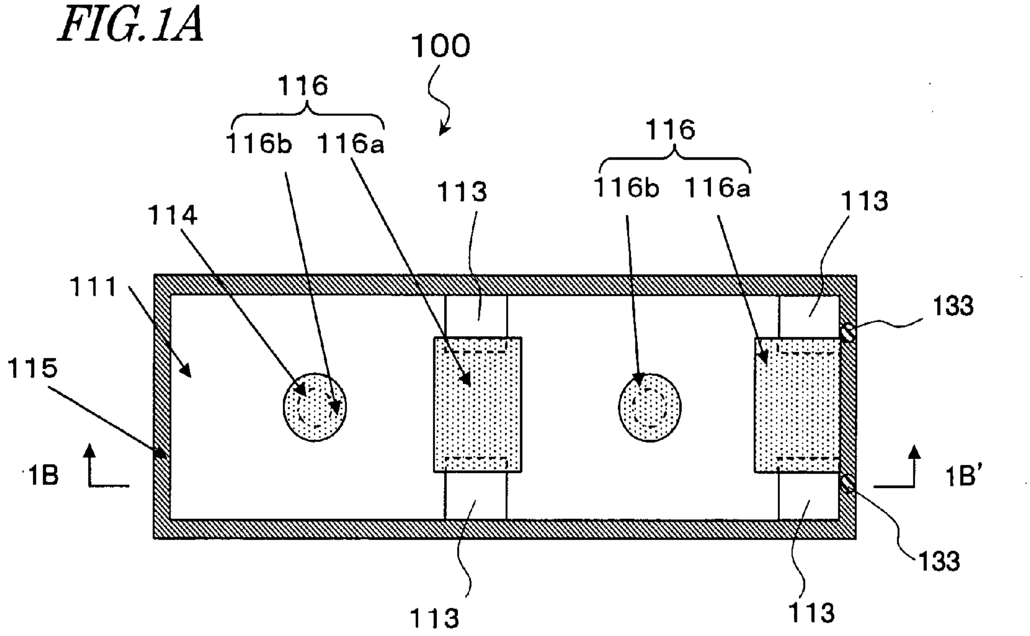

100
116
116b
116a
113
114
111
115
1B
1B'
133
113

FIG.1B

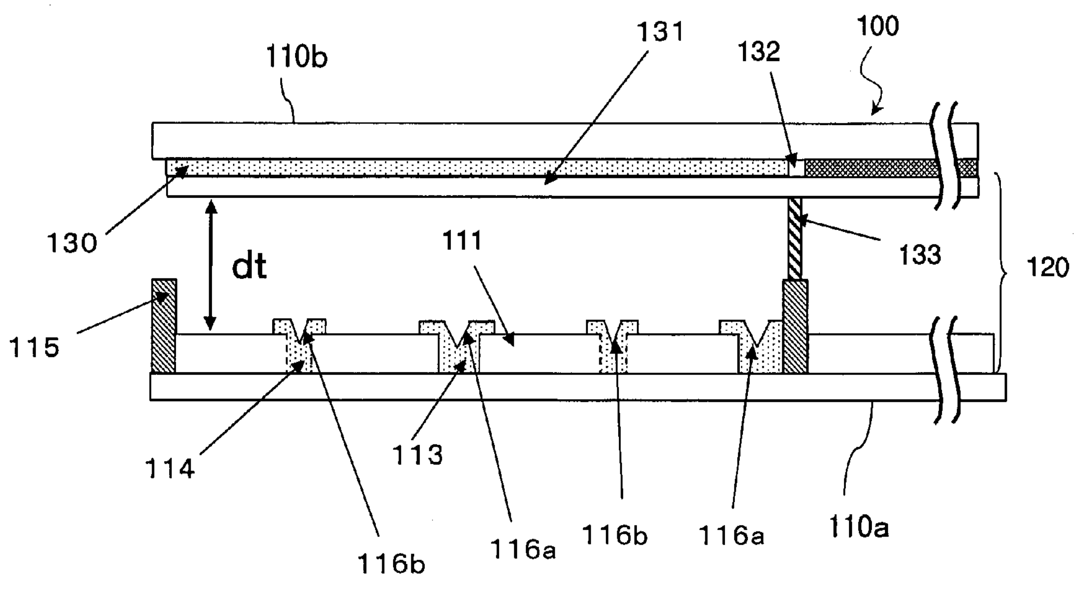
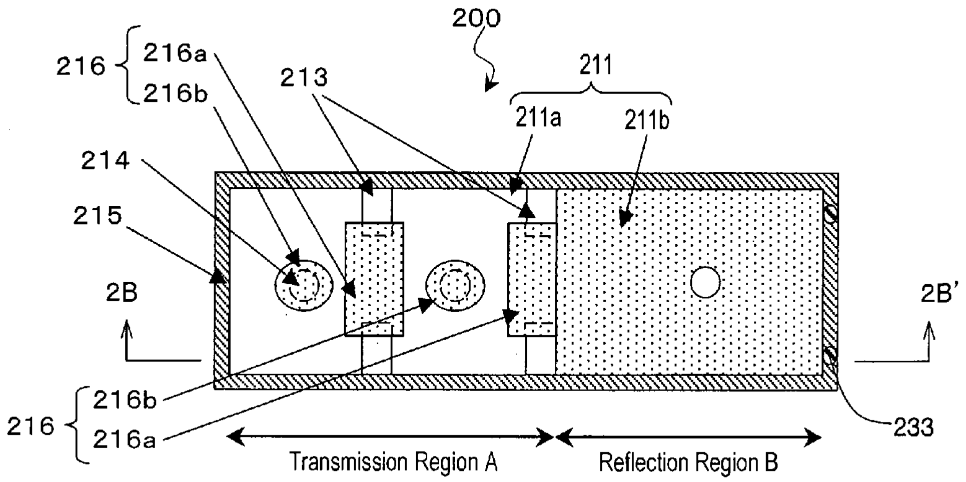
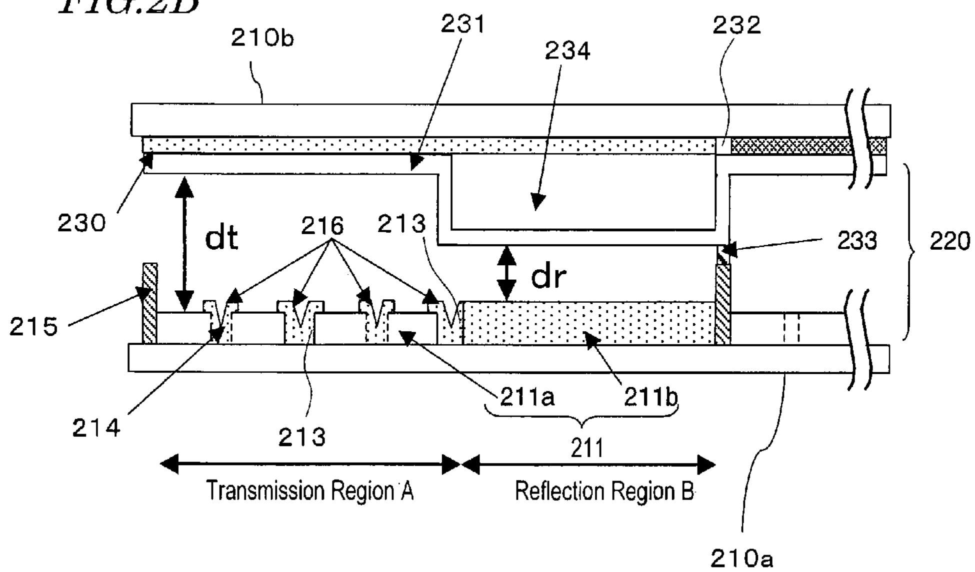

110b
131
132
100
130
dt
111
133
120
115
114
113
116b
116a
110a

FIG.2A



200
211
216
216a
216b
213
211a
211b
214
215
2B
2B'
216b
216
216a
233
Transmission Region A
Reflection Region B


FIG.2B



210b
231
234
232
230
dt
216
213
233
220
dr
215
214
211a
211b
213
211
Transmission Region A
Reflection Region B
210a

*FIG.3*

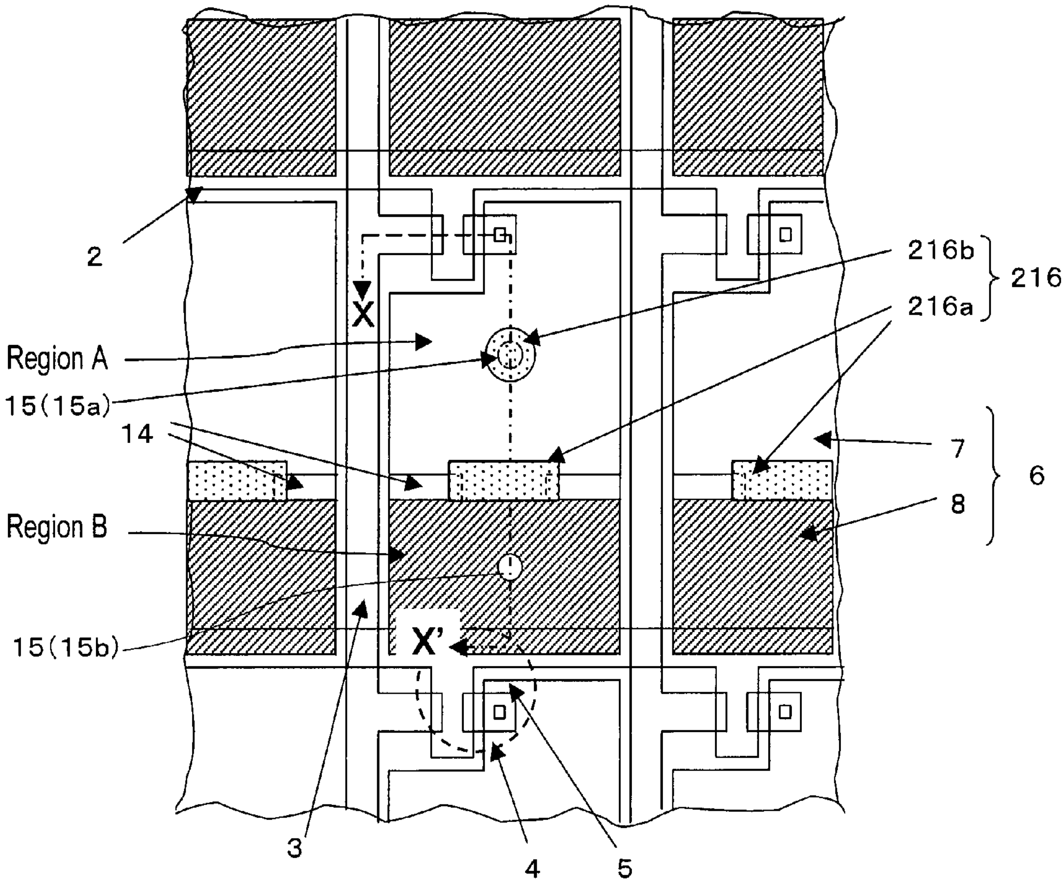


*FIG. 4*

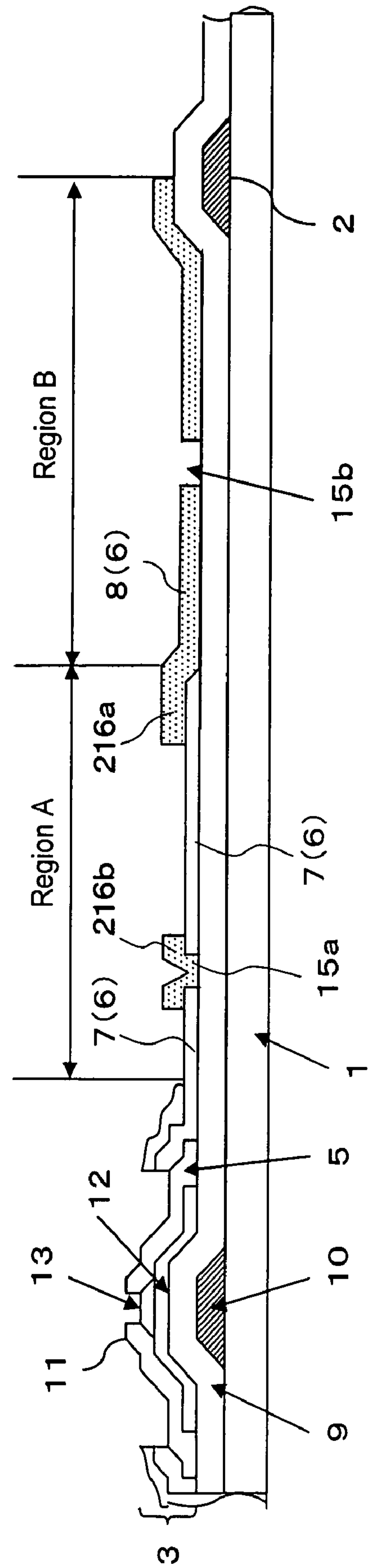


FIG.5A

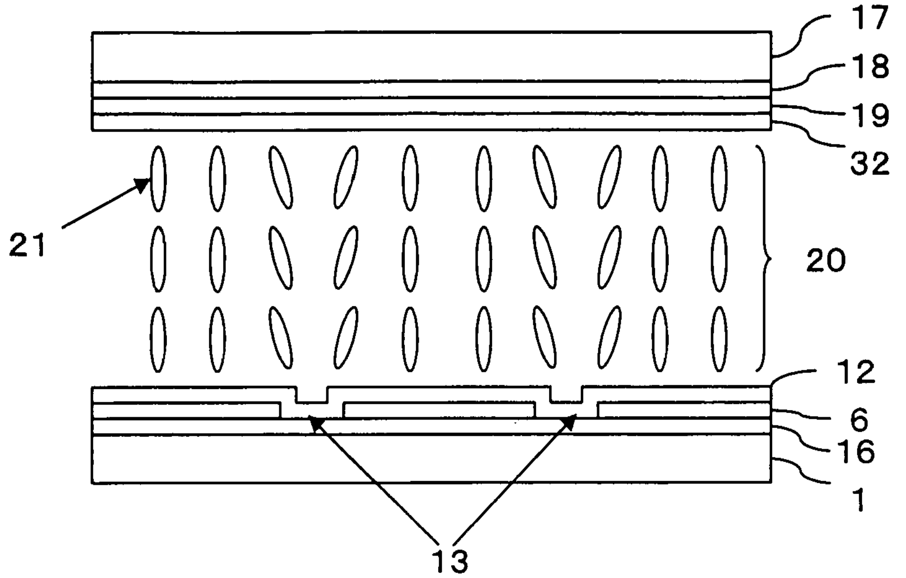



FIG.5B

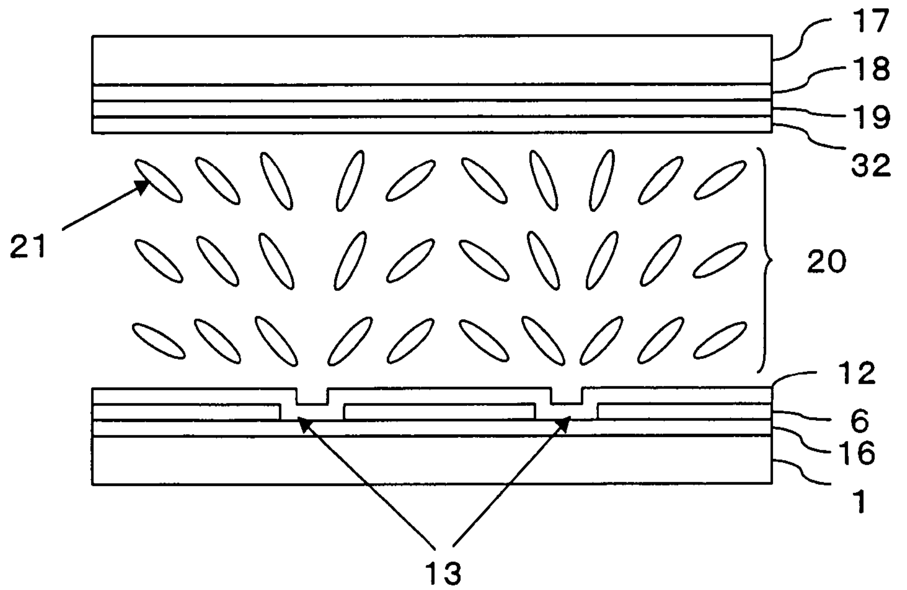


*FIG. 6A*

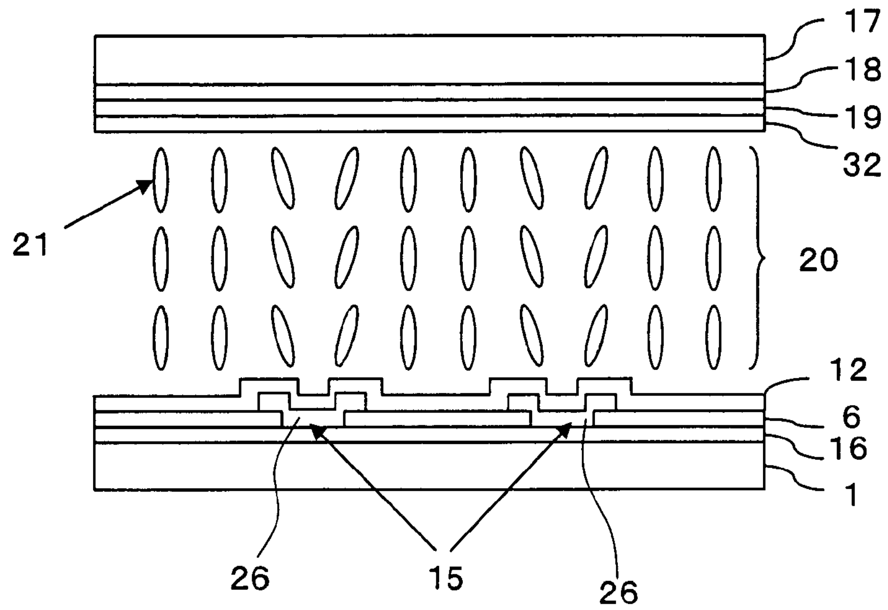



*FIG. 6B*

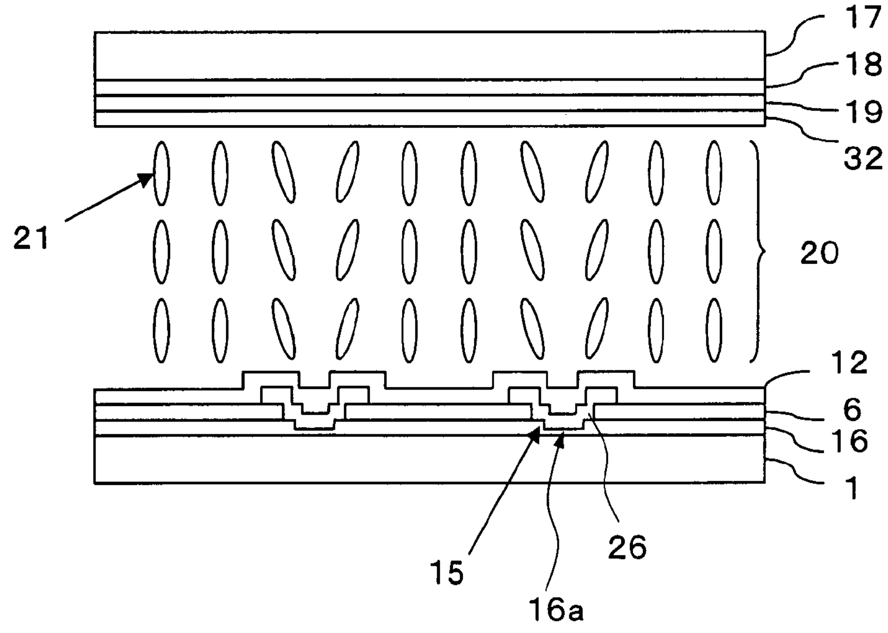


*FIG. 7*

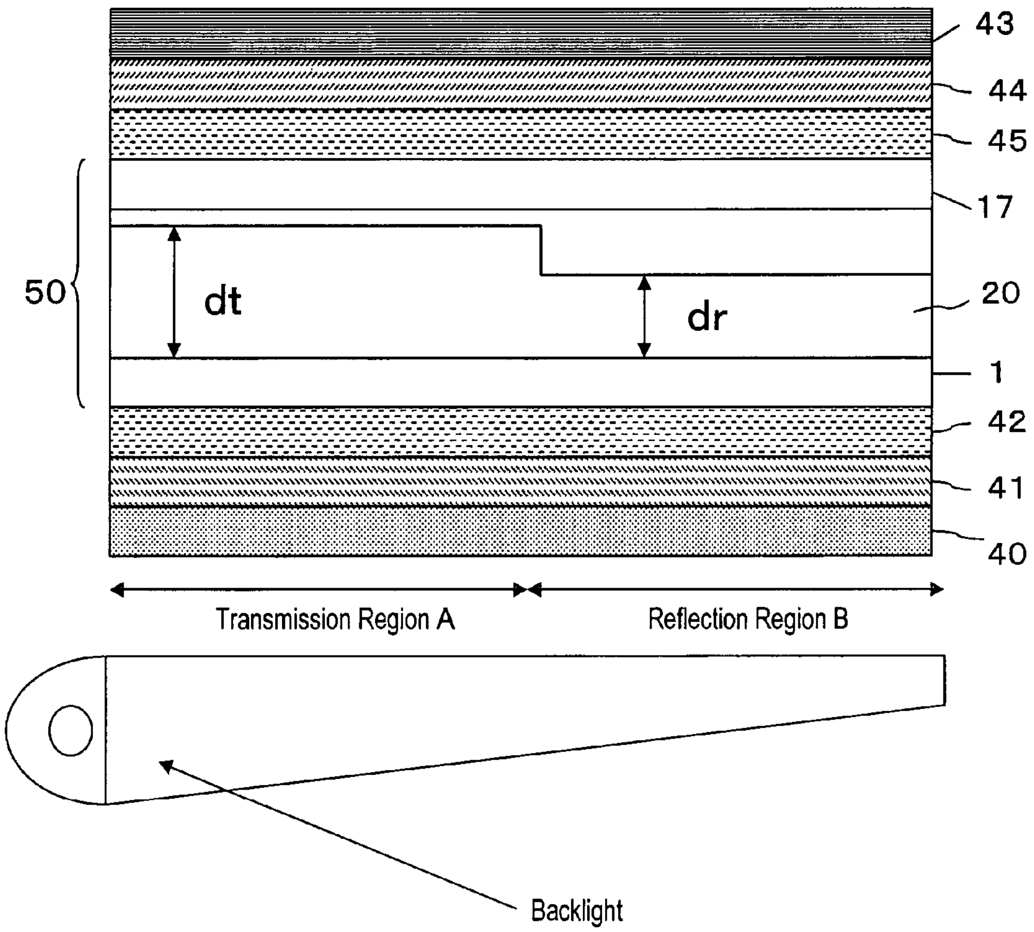

43
44
45
17
50
dt
dr
20
1
42
41
40
Transmission Region A
Reflection Region B
Backlight

*FIG.8*

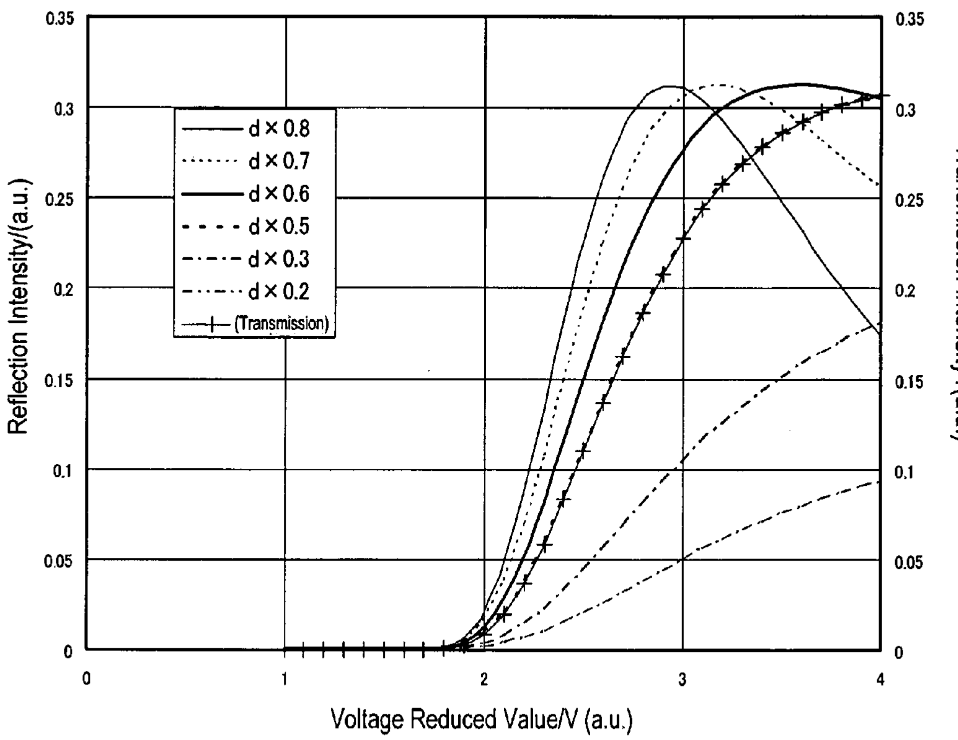



*FIG.9*

CR>10

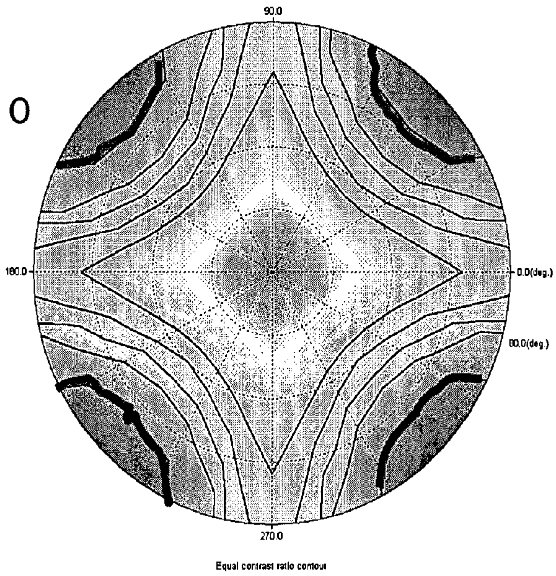


FIG. 10A

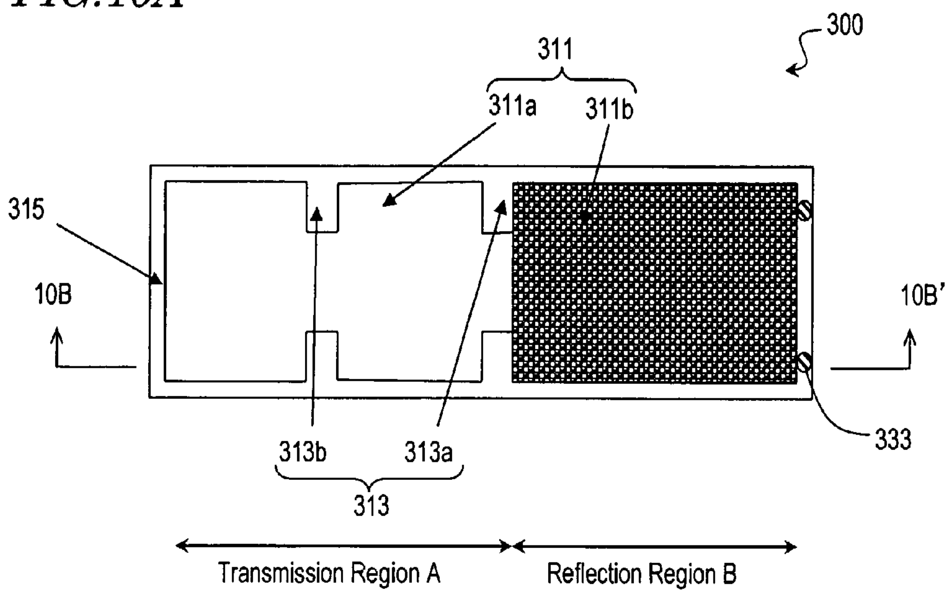



FIG. 10B

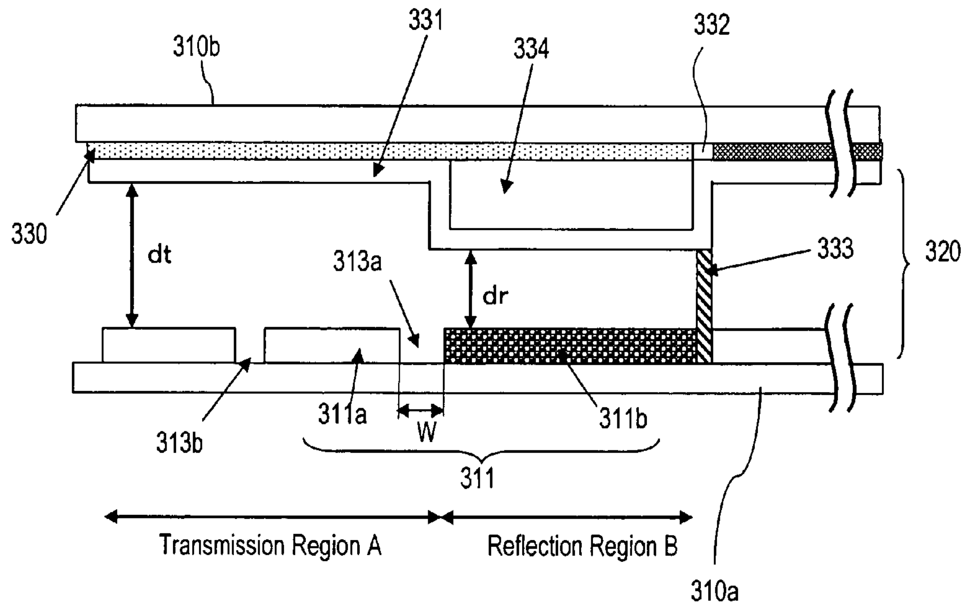


*FIG.11*

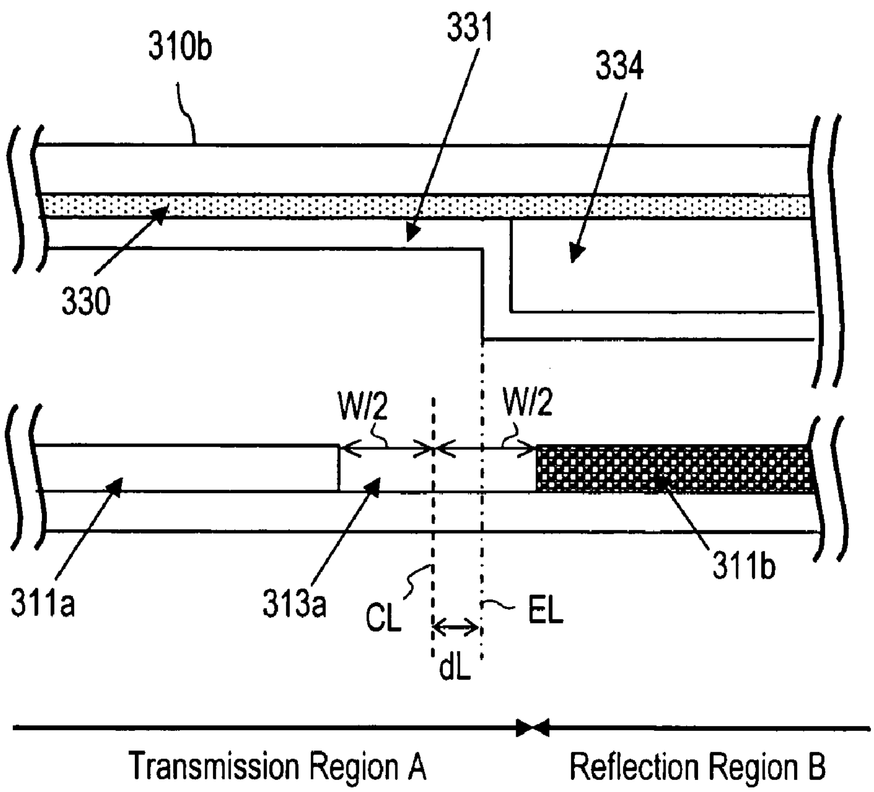

310b
331
334
330
W/2
W/2
311a
313a
CL
EL
dL
311b
Transmission Region A
Reflection Region B

*FIG.12A*

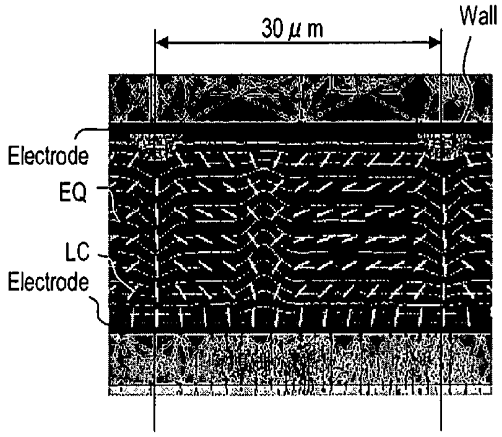



*FIG.12B*

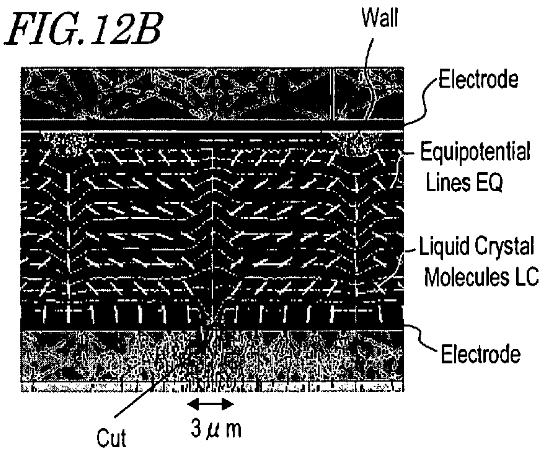



*FIG.12C*

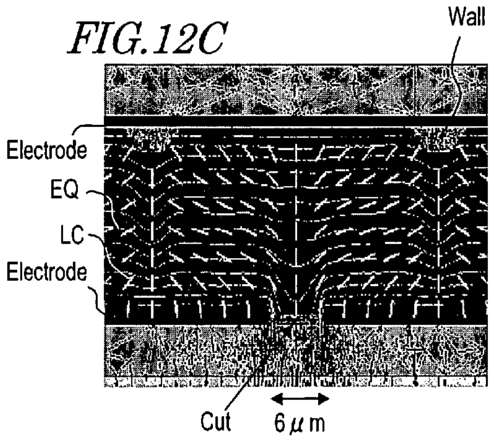



*FIG.12D*

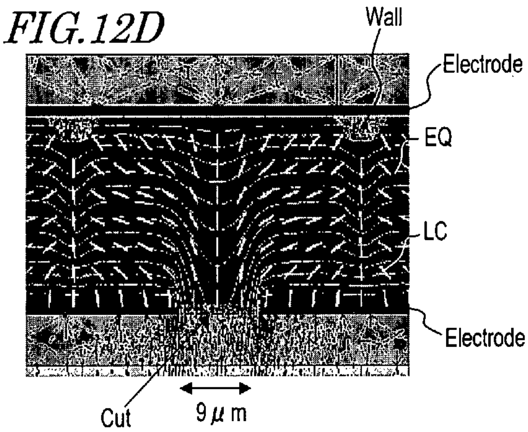



*FIG.12E*

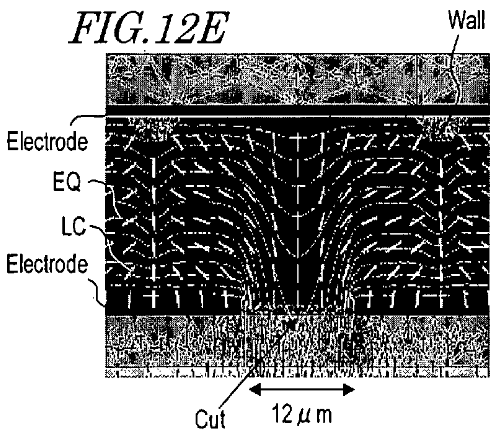



*FIG.12F*

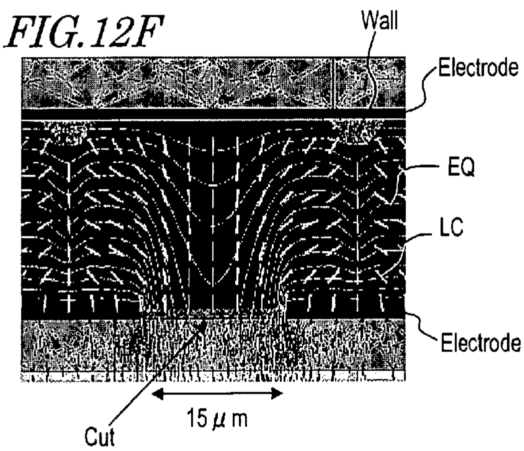


FIG. 13

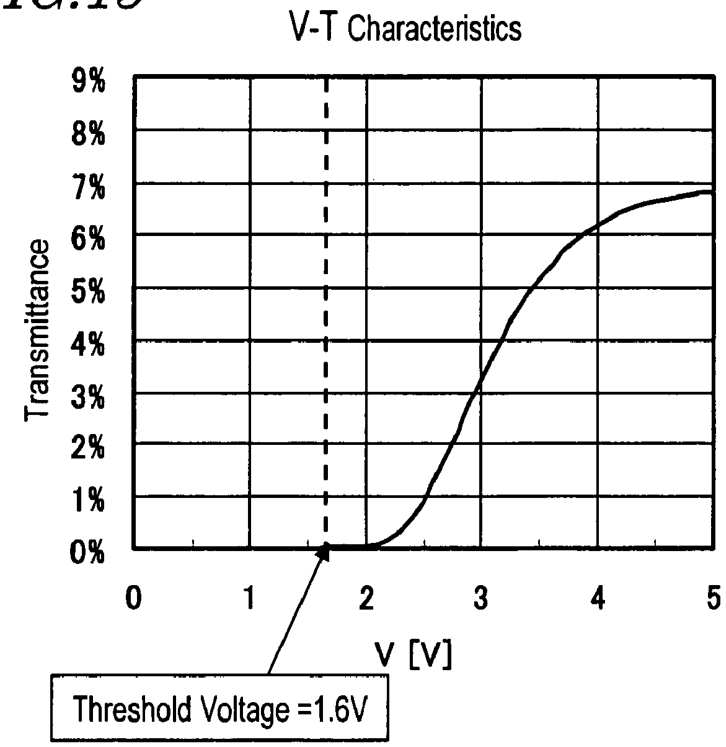

V-T Characteristics
Transmittance
9%
8%
7%
6%
5%
4%
3%
2%
1%
0%
0
1
2
3
4
5
V [V]
Threshold Voltage =1.6V

FIG. 14

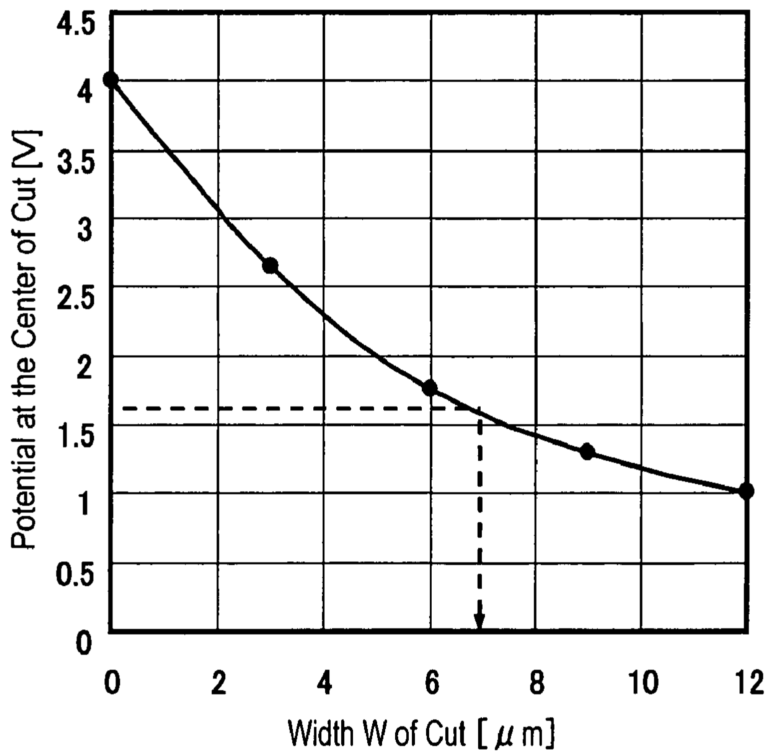

Potential at the Center of Cut [V]
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0
2
4
6
8
10
12
Width W of Cut [μm]

FIG.15A

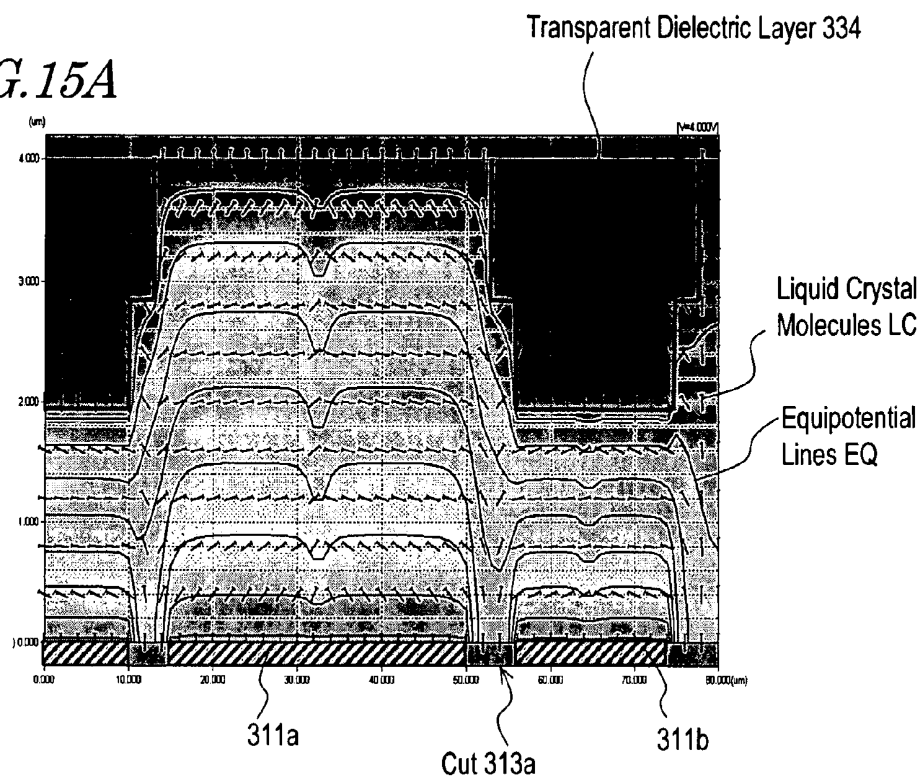
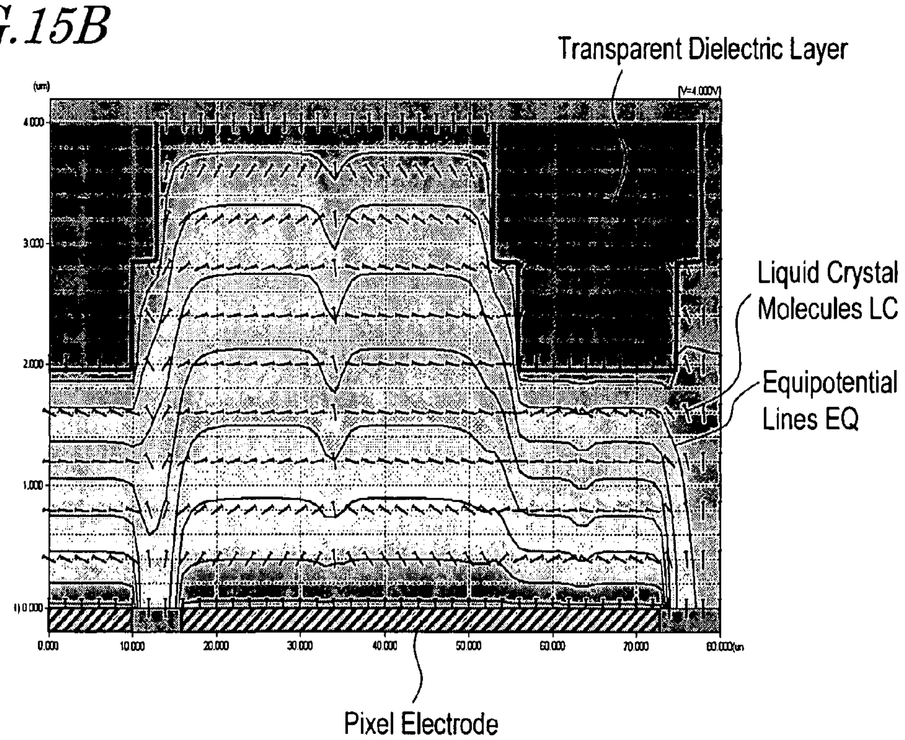



FIG.15B



# LIQUID CRYSTAL DISPLAY DEVICE COMPRISING A SHADING CONDUCTIVE LAYER FORMED AT LEAST NEAR AN OPENING OR CUT OF AN ELECTRODE

## BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a liquid crystal display device and more particularly relates to a liquid crystal display device suitably used for portable information terminals (for example, PDAs), mobile phones, car-mounted liquid crystal displays, digital cameras, PCs, amusement equipment, TVs and the like.

2. Description of the Related Art

The information infrastructure is advancing day to day, and equipment such as mobile phones, PDAs, digital cameras, video cameras and car navigators has penetrated deeply into people's lives. Liquid crystal display (LCD) devices have been adopted in most of such equipment. With increase of the information amount handled with the main bodies of the equipment, LCD devices are requested to display a larger amount of information, and are demanded by the market for higher contrast, a wider viewing angle, higher brightness, multiple colors and higher definition.

A vertical alignment mode using a vertically aligned liquid crystal layer has increasingly received attention as a display mode enabling high contrast and a wide viewing angle. The vertically aligned liquid crystal layer is generally obtained using a vertical alignment film and a liquid crystal material having negative dielectric anisotropy.

For example, Japanese Laid-Open Patent Publication No. 6-301036 (Literature 1) discloses an LCD device in which an inclined electric field is generated around an opening formed in a counter electrode that faces a pixel electrode via a liquid crystal layer, so that liquid crystal molecules surrounding liquid crystal molecules existing in the opening, which are in the vertically aligned state, are aligned in inclined directions around the opening as the center, to thereby improve the visual angle characteristics.

However, in the device described in Literature 1, it is difficult to generate an inclined electric field over the entire region of each pixel. Therefore, each pixel has a region in which liquid crystal molecules delay in response to a voltage, and this causes a problem of occurrence of an afterimage phenomenon.

To solve the above problem, Japanese Laid-Open Patent Publication No. 2000-47217 (Literature 2) discloses an LCD device in which a plurality of openings regularly arranged are provided in a pixel electrode or a counter electrode, to form a plurality of liquid crystal domains each having axisymmetric alignment in each pixel.

Japanese Laid-Open Patent Publication No. 2003-167253 (Literature 3) discloses a technology in which a plurality of projections are provided regularly in each pixel to stabilize the aligned state of liquid crystal domains having radially inclined alignment formed around the projections. This literature also discloses using an inclined electric field generated at openings formed in an electrode, together with the alignment regulating force of the projections, to regulate the alignment of liquid crystal molecules, and thus improve the display characteristics.

Japanese Laid-Open Patent Publication No. 11-242225 (Literature 4) discloses a vertically aligned LCD device (MVA LCD device) having a plurality of slits (openings or cuts) extending in parallel with one another and projections or depressions formed in an electrode in each pixel.



In recent years, a type of LCD device providing high-quality display both outdoors and indoors has been proposed (see Japanese Patent Gazette No. 2955277 (Literature 5) and U.S. Pat. No. 6,195,140 (Literature 6), for example). In this type of LCD device, called a transflective LCD device, each pixel has a reflection region in which display is done in the reflection mode and a transmission region in which display is done in the transmission mode.

The currently available transflective LCD devices adopt an ECB mode, a TN mode and the like. Literature 3 described above also discloses adoption of the vertical alignment mode for, not only a transmissive LCD device, but also a transflective LCD device. Japanese Laid-Open Patent Publication No. 2002-350853 (Literature 7) discloses a technology in which in a transflective LCD device having a vertically aligned liquid crystal layer, the alignment (multi-axis alignment) of liquid crystal molecules is controlled with depressions formed on an insulating layer. The insulating layer is provided to make the thickness of the liquid crystal layer in a transmission region twice as large as that in a reflection region. According to this literature, the depressions are in the shape of a regular octagon, for example, and projections or slits (electrode openings) are formed at positions opposed to the depressions via the liquid crystal layer (see FIGS. **4** and **16** of Literature 7, for example).

In the devices having openings and/or cuts in electrodes in pixels as described in Literature 1 to 4, problems such as overetching and peeling off of a conductive film constituting the electrodes may occur in formation of the openings and cuts by etching, and as a result, the electrodes may be cut off and regions having no voltage supply may be formed. Formation of regions shut off from supply of a predetermined voltage in pixels will be recognized as display defects (black points in normally black mode display).

Also, when openings or cuts (electrical alignment regulating structure) and projections and depressions (physical alignment regulating structure) are provided as alignment regulating structures as described in Literature 1 to 7, liquid crystal molecules near such alignment regulating structures are inclined more greatly (closer to the horizon) than liquid crystal molecules in the other regions. Regions having such alignment regulating structures are therefore observed as brighter than the other regions in normally black display. In particular, the physical alignment regulating structures, which use the effect of the shapes of the projections and depressions and the like, exert their alignment regulating forces even during non-voltage application. Light leakage therefore occurs even in the black display state and this causes decrease in contrast ratio.

In view of the above, a major object of the present invention is providing a liquid crystal display device in which occurrence of display defects caused by cutting off of electrodes in pixels, which may otherwise occur when openings or cuts are formed in the electrodes, is prevented. Another object of the present invention is providing a liquid crystal display device in which reduction in contrast ratio due to light leakage, which may otherwise occur with alignment regulating structures formed in pixels, is suppressed.

Yet another object of the present invention is providing a transflective liquid crystal display device having a transparent dielectric layer in each reflection region, which has improved display quality.

## SUMMARY OF THE INVENTION

In order to overcome the problems described above, the liquid crystal display device according to the first aspect of the present invention includes a first substrate, a second substrate opposed to the first substrate, and a vertically aligned liquid crystal layer interposed between the first substrate and the second substrate, wherein the liquid crystal display device has a plurality of pixels, each pixel including a first electrode formed on the first substrate, a second electrode formed on the second substrate, and the liquid crystal layer interposed between the first electrode and the second electrode, the first electrode has at least one opening or cut formed at a predetermined position in the pixel, at least one shading conductive layer electrically connected to the first electrode is formed at least near the at least one opening or cut, and in each of the plurality of pixels, a plurality of regions in which the directions of tilt of liquid crystal molecules are different from one another are formed when at least a predetermined voltage is applied across the liquid crystal layer.

In one embodiment, in each of the plurality of pixels, at least one liquid crystal domain exhibiting axisymmetric alignment is formed when at least a predetermined voltage is applied across the liquid crystal layer.

In another embodiment, the at least one shading conductive layer includes a shading conductive layer covering at least part of the at least one opening or cut.

In yet another embodiment, the at least one opening or cut includes two cuts opposed each other, and the at least one shading conductive layer includes a first shading conductive layer covering the two opposing sides of the two cuts. The at least one shading conductive layer is not necessarily formed to cover a region including the two opposing sides of the two cuts, but may be formed between the two opposing sides.

In one embodiment, the at least one opening or cut includes at least two openings, and the at least one shading conductive layer includes at least two shading conductive layers covering the at least two openings.

In another embodiment, the liquid crystal layer has at least two liquid crystal domains each exhibiting axisymmetric alignment when at least a predetermined voltage is applied, and the center axes of the axisymmetric alignment of the at least two liquid crystal domains are formed in or near the at least two openings.

In another embodiment, the shading conductive layer is formed of a metal film.

In yet another embodiment, the metal film includes at least one kind of metal element selected from the group consisting of Al, Ag, Ti, Ta, Mo and W.

In yet another embodiment, the device further includes a shading region in the gaps between the plurality of pixels, and a wall structure regularly arranged on the surface of the first substrate facing the liquid crystal layer in the shading region.

In yet another embodiment, the second electrode has at least one further opening formed at a predetermined position in the pixel, and the center axis of axisymmetric alignment of the at least one liquid crystal domain formed when at least a predetermined voltage is applied across the liquid crystal layer is formed in or near the at least one further opening.

In yet another embodiment, at least one further shading conductive layer electrically connected to the second electrode is formed to cover the at least one further opening.

In yet another embodiment, the first electrode includes a transparent electrode defining a transmission region and a reflective electrode defining a reflection region, and the thickness dt of the liquid crystal layer in the transmission region and the thickness dr of the liquid crystal layer in the reflection region satisfy the relationship 0.3 dt<dr<0.7 dt.

In yet another embodiment, the first electrode includes a transparent electrode defining a transmission region and a reflective electrode defining a reflection region, the at least one liquid crystal domain includes a liquid crystal domain formed in the transmission region, the at least one opening or cut includes an opening corresponding to the center axis of the liquid crystal domain formed in the transmission region and a plurality of cuts formed point-symmetrically with respect to the opening.

In yet another embodiment, the reflective electrode and the at least one shading conductive layer are formed from a same metal film.

In yet another embodiment, a transparent dielectric layer is formed selectively on the second substrate in the reflection region.

In yet another embodiment, the device further includes: a pair of polarizing plates placed to face each other via the first substrate and the second substrate; and at least one biaxial optical anisotropic medium layer placed between the first substrate and one of the pair of polarizing plates and/or between the second substrate and the other polarizing plate.

In yet another embodiment, the device further includes: a pair of polarizing plates placed to face each other via the first substrate and the second substrate; and at least one uniaxial optical anisotropic medium layer placed between the first substrate and one of the pair of polarizing plates and/or between the second substrate and the other polarizing plate.

The liquid crystal display device according to the second aspect of the present invention includes a first substrate, a second substrate opposed to the first substrate, and a vertically aligned liquid crystal layer interposed between the first substrate and the second substrate, wherein the liquid crystal display device has a plurality of pixels, each pixel including a first electrode formed on the first substrate, a second electrode formed on the second substrate, and the liquid crystal layer interposed between the first electrode and the second electrode, the first electrode has a transparent electrode defining a transmission region, a reflective electrode defining a reflection region, and a cut formed between the transparent electrode and the reflective electrode, the second substrate further has a transparent dielectric layer in the reflection region, the thickness dt of the liquid crystal layer in the transmission region and the thickness dr of the liquid crystal layer in the reflection region satisfy the relationship 0.3 dt<dr<0.7 dt, the transparent dielectric layer has an end face coinciding the center of the width of the cut or located on the side of the reflective electrode with respect to the center, and the liquid crystal layer has at least one liquid crystal domain exhibiting axisymmetric alignment in each of the transmission region and the reflection region when at least a predetermined voltage is applied.

In one embodiment, the potential at the center of the cut is lower than a threshold voltage of the liquid crystal layer when a white voltage is applied across the liquid crystal layer.

The liquid crystal display device according to the second aspect of the invention can be combined with the liquid crystal display device according to the first aspect described above.

In the liquid crystal display device according to the first aspect of the invention, at least one opening or cut is provided in an electrode in each pixel to form a plurality of regions in which the directions of tilt of liquid crystal molecules are different from one another when at least a predetermined voltage is applied across the liquid crystal layer. At least part of the opening or cut is covered with a shading conductive layer (for example, a metal layer) that is electrically connected to the electrode. Hence, even if overetching, peeling off of a conductive film constituting the electrode and the like occurs during formation of the opening or cut by etching, electric connection is ensured with the shading conductive layer, and thus formation of a region shut off from supply of a predetermined voltage in the pixel is prevented. As a result, occurrence of a display defect is suppressed/prevented. Also, by covering the opening formed to fix the center axis of axisymmetric alignment with a shading conductive layer, light leakage near the opening can be minimized/prevented.

In the liquid crystal display device according to the second aspect of the invention, which is a transflective liquid crystal layer having a transparent dielectric layer in the reflection region, the transparent dielectric layer is placed so that its end face coincides with the center of the width of a cut or is located on the side of the reflective electrode with respect to the center. Hence, the axisymmetric alignment formed in the transmission region and the reflection region is stabilized, and this improves the display quality. Naturally, a liquid crystal display device having both features of the constructions of the first and second aspects has the effects of both devices.

Other features, elements, processes, steps, characteristics and advantages of the present invention will become more apparent from the following detailed description of preferred embodiments of the present invention with reference to the attached drawings.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. **1**A and **1**B diagrammatically show one pixel of a transmissive LCD device **100** of an embodiment according to the first aspect of the present invention, in which FIG. **1**A is a plan view and FIG. **1**B is a cross-sectional view taken along line **1**B-**1**B' in FIG. **1**A.

FIGS. **2**A and **2**B diagrammatically show one pixel of a transflective LCD device **200** of an embodiment according to the first aspect of the present invention, in which FIG. **2**A is a plan view and FIG. **2**B is a cross-sectional view taken along line **2**B-**2**B' in FIG. **2**A.

FIG. **3** is a plan view of an active matrix substrate **210***a* of the transflective LCD device **200**.

FIG. **4** is a cross-sectional view of the active matrix substrate **210***a* of the transflective LCD device **200**.

FIGS. **5**A and **5**B are diagrammatic views for demonstrating the operation principle of an LCD device of the present invention, showing the states during non-voltage application (FIG. **5**A) and during voltage application (FIG. **5**B).

FIGS. **6**A and **6**B are other diagrammatic views for demonstrating the operation principle of LCD devices of the present invention, showing the construction having shading conductive layers covering openings (FIG. **6**A) and the construction in which an insulating layer underlying the openings have depressions (FIG. **6**B).

FIG. **7** is a diagrammatic view showing an example of construction of an LCD device of an embodiment of the present invention.

FIG. **8** is a graph showing the dependence of the voltage-reflectance (transmittance) of a transmission region and a reflection region on the thickness of the liquid crystal layer in an LCD device of an embodiment of the present invention.

FIG. **9** is a view showing the visual angle—contrast ratio characteristics of an LCD device of an embodiment of the present invention.

FIGS. **10**A and **10**B diagrammatically show one pixel of a transflective LCD device **300** of an embodiment according to the second aspect of the present invention, in which FIG. **10**A is a plan view and FIG. **10**B is a cross-sectional view taken along line **10**B-**10**B' in FIG. **10**A.

FIG. **11** is an enlarged view of the boundary between a reflection region and a transmission region in FIG. **10**B.

FIGS. **12**A through **12**F are views diagrammatically showing liquid crystal molecules LC and equipotential lines EQ of an electric field generated in a liquid crystal layer, observed 200 msec after application of a white voltage across the liquid crystal layer, in the cases that no cut is formed (FIG. **12**A), the width W of a cut is 3 μm (FIG. **12**B), 6 μm (FIG. **12**C), 9 μm (FIG. **12**D), 12 μm (FIG. **12**E) and 15 μm (FIG. **12**F).

FIG. **13** is a graph showing the voltage-transmittance characteristics of a liquid crystal display device.

FIG. **14** is a graph showing the results of calculation of the relationship between the width W of a cut and the potential at the center (position of W/2) of the cut.

FIG. **15**A is a view diagrammatically showing equipotential lines EQ of an electric field generated in a liquid crystal layer near a cut **313***a* and the alignment of liquid crystal molecules LC in the liquid crystal display device of the embodiment, and FIG. **15**B is a view diagrammatically showing equipotential lines EQ of an electric field generated in a liquid crystal layer and the alignment of liquid crystal molecules LC in the case of providing no cuts.

## DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Hereinafter, preferred embodiments of the present invention will be described with reference to the accompanying drawings.

(Transmissive LCD Device)

A transmissive LCD device **100** of an embodiment according to the first aspect of the present invention will be described with reference to FIGS. **1**A and **1**B. FIGS. **1**A and **1**B diagrammatically show one pixel of the transmissive LCD device **100**, in which FIG. **1**A is a plan view and FIG. **1**B is a cross-sectional view taken along line **1**B-**1**B' in FIG. **1**A.

Hereinafter, described will be the case that one pixel is divided into two parts (N=2). The number of parts into which one pixel is divided (=N) can also be three or more depending on the pixel pitch. In any case, the number of openings (=n) each to be positioned roughly in the center of a divided region on a second substrate, in this case, is preferably the same as the number of divided parts (=N). The effective aperture ratio tends to decrease with increase of the number of divided parts (=N). Therefore, for an application to a high-definition display panel, the number of divided parts (=N) is preferably made small. The present invention is also applicable to the case involving no pixel division (this may be expressed as N=1). Each of the divided regions may be called a "sub-pixel". One liquid crystal domain is typically formed in each sub-pixel.

The LCD device **100** includes a transparent substrate (for example, a glass substrate) **110***a*, a transparent substrate **110***b* placed to face the transparent substrate **110***a*, and a vertically aligned liquid crystal layer **120** interposed between the transparent substrates **110***a* and **110***b*. Vertical alignment films (not shown) are formed on the surfaces of the substrates **110***a* and **110***b* facing the liquid crystal layer **120**. During non-voltage application, therefore, liquid crystal molecules in the liquid crystal layer **120** are aligned roughly vertical to the surfaces of the vertical alignment films. The liquid crystal layer **120** includes a nematic liquid crystal material having negative dielectric anisotropy and also includes a chiral agent as required.

The LCD device **100** further includes pixel electrodes **111** formed on the transparent substrate **110***a* and a counter electrode **131** formed on the transparent substrate **110***b*. Each pixel electrode **111**, the counter electrode **131** and the liquid crystal layer **120** interposed between these electrodes define a pixel. In the illustrated example, both the pixel electrodes **111** and the counter electrode **131** are formed of a transparent conductive film (for example, an ITO film). Typically, color filters **130** (the entire of the plurality of color filters may also be called a color filter layer **130**) provided for the respective pixels, as well as a black matrix (shading layer) **132** formed in the gaps between the adjacent color filters **130**, are formed on the surface of the transparent substrate **110***b* facing the liquid crystal layer **120**, and the counter electrode **131** is formed on the color filters **130** and the black matrix **132**. Alternatively, the color filters **130** and the black matrix **132** may be formed on the counter electrode **131** (on the surface thereof facing the liquid crystal layer **120**).

In the LCD device **100** shown in FIGS. **1**A and **1**B, in which the number of divided parts (=N) is 2, a wall structure **115** to be described later extends on the transparent substrate **110***a* in a shading region around the pixel electrodes **111**. Each pixel electrode **111** has openings **114** of the number corresponding to the number of divided parts (n=2 in the illustrated example) at predetermined positions in the pixel, and also has four cuts **113** at predetermined positions. The LCD device **100** also includes a shading conductive layer **116** formed at predetermined positions in each pixel. The illustrated shading conductive layer **116** has shading conductive layers **116***b* formed to cover the openings **114** in the pixel electrode **111** and shading conductive layers **116***a* formed to cover part of the cuts **113**. Each of the shading conductive layers **116***a* covering part of the cuts **113** is placed to cover a region including two opposing sides of the two cuts **113** opposed each other.

When a predetermined voltage is applied across the liquid crystal layer **120**, two (number equal to the number of divided parts N) liquid crystal domains each having axisymmetric alignment are formed, with the center axes of the axisymmetric alignment thereof being in or near the openings **114** (that is, in or near depressions formed on the surfaces of the shading conductive layers **116***b* in correspondence with the openings **114**). As will be described later in detail, the openings **114** (the depressions of the shading conductive layers **116***b*) act to fix the positions of the center axes of the axisymmetrically aligned domains.

The cuts **113**, provided in the pixel electrode **111** near the boundaries of the axisymmetrically aligned domains, define the directions in which liquid crystal molecules fall with an electric field, and thus act to form the axisymmetrically aligned domains. An inclined electric field is generated around the cuts **113** with a voltage applied between the pixel electrode **111** and the counter electrode **131**. With this inclined electric field, the directions of tilt of liquid crystal molecules are defined. The wall structure **115** also acts to define the directions of tilt of liquid crystal molecules during voltage application (during generation of an electric field) with its slope face effect. The alignment regulating force of the slope faces of the wall structure **115** acts even during non-voltage application, causing liquid crystal molecules to tilt. During voltage application, the inclined electric field generated with the cuts **113** and the action of an electric field distorted with the wall structure **115** define the directions of tilt of liquid crystal molecules, resulting in formation of the axisymmetric alignment as described above. In the illustrated example, a total of four cuts **113** are given point-symmetrically with respect to the opening **114** (in this case, the right opening as viewed from FIG. **1**A) corresponding to the center axis of a liquid crystal domain formed in the pixel (in this case, the entire pixel is a transmission region). By providing the cuts **113** as described above, the directions in which liquid crystal molecules fall during voltage application are defined, allowing formation of two liquid crystal domains. The shape of the cuts **113** acting to define the directions in which liquid crystal molecules in axisymmetrically aligned domains fall with an electric field is determined so that roughly the same alignment regulating force can be exerted to the adjacent axisymmetrically aligned domains, and is preferably a tetragon, for example.

The reason why no cuts are provided on the left side of the pixel electrode **111** as viewed from FIG. **1**A is that substantially the same function is obtained from cuts provided on the right side of the adjacent pixel electrode (not shown) located left to the illustrated pixel electrode **111**, and thus cuts, which may decrease the effective aperture ratio of the pixel, are omitted on the left side of the pixel electrode **111**. Also, in the illustrated example, the wall structure **115** to be described later gives the alignment regulating force. Therefore, with no cuts provided on the left side of the pixel electrode **111**, the resultant liquid crystal domain is as stable as a liquid crystal domain having such cuts. In addition, the effect of improving the effective aperture ratio is obtained.

Although a total of four cuts **113** were formed in the illustrated example, at least one cut between the adjacent liquid crystal domains is sufficient. For example, an elongate cut may be formed in the center of the pixel and the other cuts may be omitted.

Each of the shading conductive layers **116***a* is formed to cover a region including two opposing sides of the two cuts **113** opposed each other. In formation of the cuts **113** by etching, overetching, peeling off of a conductive film (an ITO film in the illustrated example) constituting the pixel electrode **111** and the like may occur and, as a result, the conductive film constituting the pixel electrode **111** may be cut off. Even in such a case, electrical connection can be secured with the shading conductive layer **116***a*, and thus formation of a region shut off from supply of a predetermined voltage in the pixel is prevented. Hence, it is possible to prevent/suppress occurrence of a display defect due to cutting off (disconnection) of the pixel electrode **111**.

The shading conductive layer **116***a* is not necessarily formed to cover a region including two opposing sides of two cuts **113**, but may be formed between the two opposing sides. For example, in an etching process, a crack so long as to connect the two cuts **113** may be produced in a conductive film constituting the pixel electrode **111**, and this may result in cutting off of the conductive film causing connection failure in the pixel electrode. To prevent such disconnection in the pixel electrode due to a crack, the shading conductive layer **116***a* does not necessarily overlap part of the cuts **113** but may only be formed on a portion in which a crack is likely to occur (in the illustrated example, a portion between the two opposing sides of the two cuts **113**). In other words, connection failure as described above can be prevented by forming a shading conductive layer at least in the vicinity of the cuts **113** (or openings) in which a crack is likely to occur.

The openings **114** are formed to fix the center axes of the axisymmetrically aligned domains. With the openings **114** formed in the pixel electrode **111**, depressions are formed on the surfaces of the shading conductive layers **116***b* covering the openings **114**. With the effect of the shape of the depressions, the directions of tilt of liquid crystal molecules are defined and the center axes of the axisymmetric alignment are fixed/stabilized. The shape of the openings **114** for formation of the depressions for fixing the center axes of the axisymmetrically aligned domains is preferably circular as illustrated, but not limited to this. To exert roughly equal alignment regulating force in all directions, the shape is preferably a polygon having four or more sides and more preferably a regular polygon.

The shading conductive layers **116***b* covering the openings **114** act to suppress light leakage from near the center axes of the axisymmetric alignment formed in about the center of the liquid crystal domains. As described above, liquid crystal molecules near the alignment regulating structures are inclined more greatly (closer to the horizon) than liquid crystal molecules in the other regions. Regions having such alignment regulating structures are therefore observed as brighter than the other regions in the normally black display. In particular, the physical alignment regulating structures exert their alignment regulating forces even during non-voltage application. Light leakage therefore occurs even in the black display state and this causes reduction in contrast ratio. The depressions on the surfaces of the shading conductive layers **116***b* formed with the openings **114** define the directions of tilt of liquid crystal molecules with their shape effect. In addition, each of the openings **114**, formed for fixing the center axis of the axisymmetric alignment of the liquid crystal domain, is located in about the center of the sub-pixel. If light leakage occurs near the opening **114**, therefore, reduction in contrast ratio is eminent. By providing the shading conductive layer **116***b* to cover the opening **114**, the reduction in contrast ratio can be suppressed. The shading conductive layers **116***a* formed to cover part of the cuts **113** also act to suppress light leakage near the cuts **113**. However, to ensure sufficient exertion of the effect of the inclined electric field with the cuts **113**, it is not preferred to cover a wide area of the cuts **113** with the shading conductive layers **116***a*, but is preferred to form the shading conductive layers **116***a* to selectively cover only part of the cuts **113** for prevention of occurrence of disconnection in the pixel electrode **111** as described above. The shading conductive layers **116***a* and **116***b* can be formed of the same film (metal film, for example).

The preferred size of the opening **114** depends on the size of the sub-pixel (liquid crystal domain). Preferably, however, the diameter is 10 μm or less when the opening is a circle (the length of the longest side when it is a polygon). The diameter of the shading conductive layer **116***b* covering the opening **114** (the length of the longest side when the layer is a polygon) is preferably greater by about 20% than the diameter of the opening **114** in consideration of the positioning precision. If the size of the opening **114** is greater than the above value, the area of the shading conductive layer **116***b* increases resulting in disadvantageously decreasing the effective aperture ratio. The step of the depression formed on the surface of the shading conductive layer **116***b* corresponding to the opening **114** is preferably 0.1 μm or more, more preferably 0.15 μm or more, to ensure the effect of fixing/stabilizing the center axis of the axisymmetric alignment.

The LCD device **100** has a shading region between the adjacent pixels, and the wall structure **115** is placed on the transparent substrate **110***a* in the shading region. The shading region as used herein refers to a region shaded from light due to the presence of TFTs, gate signal lines and source signal lines formed on the peripheries of the pixel electrodes **111** on the transparent substrate **110***a*, or the presence of the black matrix formed on the transparent substrate **110***b*, for example. Since this region does not contribute to display, the wall structure **115** formed in the shading region is free from adversely affecting the display.

The illustrated wall structure **115** is a continuous wall surrounding the pixel. Alternatively, the wall structure **115** may be composed of a plurality of separate walls. The wall structure **115**, which serves to define boundaries of liquid crystal domains located near the outer edges of the pixel, should preferably have a length of some extent. For example, when the wall structure is composed of a plurality of walls, each wall is preferably longer than the gap between the adjacent walls.

Supports **133** for defining the thickness of the liquid crystal layer **120** (also called the cell gap) are preferably formed in the shading region (in the illustrated example, the region defined by the black matrix **132**) to avoid degradation in display quality due to the supports. Although the supports **133** are formed on the wall structure **115** provided in the shading region in the illustrated example, the supports **133** may be formed on either transparent substrate **110***a* or **110***b*. In the case of forming the supports **133** on the wall structure **115**, setting is made so that the sum of the height of the wall structure **115** and the height of the supports **133** is equal to the thickness of the liquid crystal layer **120**. If the supports **133** are formed in a region having no wall structure **115**, setting is made so that the height of the supports **133** is equal to the thickness of the liquid crystal layer **120**. The supports **133** can be formed by photolithography using a photosensitive resin, for example.

In the LCD device **100**, when a predetermined voltage (voltage equal to or higher than a threshold voltage) is applied between the pixel electrode **111** and the counter electrode **131**, two axisymmetrically aligned regions of which the center axes are stabilized in or near the two openings **114** (depressions on the shading conductive layers **116***b*) are formed, the pair of cuts **113** formed in the center of the pixel electrode **111** in the length direction define the directions in which liquid crystal molecules in the two adjacent liquid crystal domains fall with an electric field, and the wall structure **115** and the cuts **113** formed in the corners of the pixel electrode **111** define the directions in which liquid crystal molecules in the portions of the liquid crystal domains near the outer edges of the pixel fall with the electric field. The alignment regulating forces of the openings **114**, the cuts **113** and the wall structure **115** are considered to act cooperatively, to stabilize the alignment of the liquid crystal domains.

On the surface of the transparent substrate **110***a* facing the liquid crystal layer **120**, provided are active elements such as TFTs and circuit elements such as gate signal lines and source signal lines connected to TFTs (all of these elements are not shown). Herein, the transparent substrate **110***a*, together with the circuit elements and the pixel electrodes **111**, the wall structure **115**, the supports **133**, the alignment film and the like described above formed on the transparent substrate **110***a*, are collectively called an active matrix substrate in some cases. Likewise, the transparent substrate **110***b*, together with the color filter layer **130**, the black matrix **132**, the counter electrode **131**, the alignment film and the like formed on the transparent substrate **110***b*, are collectively called a counter substrate or a color filter substrate in some cases.

In the LCD device **100** shown in FIGS. **1**A and **1**B, the alignment regulating structures such as the cuts **113**, the openings **114** and the wall structure **115** were placed only on the transparent substrate **110***a*. Alternatively, the alignment regulating structures may be formed on the transparent substrate **110***b*, or they may be formed on both transparent substrates. Placing the alignment regulating structures only on either one substrate has the advantage of simplifying the fabrication process. Placing openings for center fixing on both substrates has the advantage of further effectively fixing/stabilizing the center axis of the axisymmetric alignment, and thus reducing the display roughness and shortening the response time in grayscale display.

The wall structure **115**, exerting its alignment regulating force even during non-voltage application, has the advantage of effectively stabilizing the axisymmetric alignment in a grayscale display state, but may be omitted depending on the use of the LCD device and the like. The opening **114**, which serves to fix/stabilize the center axis of the axisymmetric alignment, provides the effect of improving the uniformity of display, but may be omitted depending on the use of the LCD device and the like.

Although omitted in the above description, the LCD device **100** further includes a pair of polarizing plates placed to face each other via the transparent substrates **110***a* and **110***b*. The polarizing plates are typically placed so that their transmission axes are orthogonal to each other. The LCD device **100** may further include a biaxial optical anisotropic medium layer and/or a uniaxial optical anisotropic medium layer, as will be described later.

(Transflective LCD Device)

Next, a transflective LCD device **200** of an embodiment according to the first aspect of the present invention will be described with reference to FIGS. **2**A and **2**B.

FIGS. **2**A and **2**B diagrammatically show one pixel of the transflective LCD device **200** of an embodiment of the present invention, in which FIG. **2**A is a plan view and FIG. **2**B is a cross-sectional view taken along line **2**B-**2**B' in FIG. **2**A.

Hereinafter, described will be a case that one pixel is divided into three parts (N=3; two for the transmission region and one for the reflection region). The number of parts into which one pixel is divided (=N) can be at least two (at least one for the transmission region and at least one for the reflection region) determined depending on the pixel pitch. The effective aperture ratio tends to decrease with increase of the number of divided parts (=N). Therefore, for an application to a high-definition display panel, the number of divided parts (=N) is preferably made small.

The LCD device **200** includes a transparent substrate (for example, a glass substrate) **210***a*, a transparent substrate **210***b* placed to face the transparent substrate **210***a*, and a vertically aligned liquid crystal layer **220** interposed between the transparent substrates **210***a* and **210***b*. Vertical alignment films (not shown) are formed on the surfaces of the substrates **210***a* and **210***b* facing the liquid crystal layer **220**. During non-voltage application, therefore, liquid crystal molecules in the liquid crystal layer **220** are aligned roughly vertical to the surfaces of the vertical alignment films. The liquid crystal layer **220** includes a nematic liquid crystal material having negative dielectric anisotropy and also includes a chiral agent as required.

The LCD device **200** further includes pixel electrodes **211** formed on the transparent substrate **210***a* and a counter electrode **231** formed on the transparent substrate **210***b*. Each pixel electrode **211**, the counter electrode **231** and the liquid crystal layer **220** interposed between these electrodes define a pixel. Circuit elements such as TFTs are formed on the transparent substrate **210***a* as will be described later. Herein, the transparent substrate **210***a* and the components formed thereon are collectively called an active matrix substrate **210***a* in some cases.

Typically, color filters **230** (the entire of the plurality of color filters may also be called a color filter layer **230**) provided for the respective pixels, as well as a black matrix (shading layer) **232** provided in the gaps between the adjacent color filters **230**, are formed on the surface of the transparent substrate **210***b* facing the liquid crystal layer **220**, and the counter electrode **231** is formed on the color filters **230** and the black matrix **232**. Alternatively, the color filters **230** and the black matrix **232** may be formed on the counter electrode **231** (on the surface thereof facing the liquid crystal layer **220**). Herein, the transparent substrate **210***b* and the components formed thereon are collectively called a counter substrate (color filter substrate) **210***b* in some cases.

Each pixel electrode **211** includes a transparent electrode **211***a* formed of a transparent conductive layer (for example, an ITO layer) and a reflective electrode **211***b* formed of a metal layer (for example, an Al layer). Having such a pixel electrode, each pixel includes a transmission region A defined by the transparent electrode **211***a* and a reflection region B defined by the reflective electrode **211***b*, to provide display in the transmission mode and display in the reflection mode, respectively.

In the LCD device **200** shown in FIGS. **2**A and **2**B, in which the number of divided parts (=N) is 3 (two for the transmission region and one for the reflection region), a wall structure **215** to be described later extends in a shading region around each pixel electrode **211**. The pixel electrode **211** has openings **214** of the number corresponding to the number of divided parts (n=3 in the illustrated example) at predetermined positions in the pixel, and also has four cuts **213** at predetermined positions. The LCD device **200** also includes a shading conductive layer **216** formed at predetermined positions in each pixel. The illustrated shading conductive layer **216** has shading conductive layers **216***b* formed to cover the openings **214** in the pixel electrode **211** and shading conductive layers **216***a* formed to cover part of the cuts **213**. Each of the shading conductive layers **216***a* covering part of the cuts **213** is placed to cover a region including two opposing sides of the two cuts **113** opposed each other.

When a predetermined voltage is applied across the liquid crystal layer, three (number equal to the number of divided parts N) liquid crystal domains each having axisymmetric alignment are formed, with the center axes of the axisymmetric alignment of the liquid crystal domains being in or near the openings **214** (that is, in or near depressions formed on the surfaces of the shading conductive layers **216***b* in correspondence with the openings **214**). As will be described later, the openings **214** (the depressions of the shading conductive layers **216***b*) formed at predetermined positions of the pixel electrode **211** act to fix the positions of the center axes of the axisymmetric alignment.

The cuts **213**, provided in the pixel electrode **211** near the boundaries of the axisymmetrically aligned domains, define the directions in which liquid crystal molecules fall with an electric field, and thus act to form the axisymmetrically aligned domains. An inclined electric field is generated around the cuts **213** with a voltage applied between the pixel electrode **211** and the counter electrode **231**. With this inclined electric field, the directions of tilt of liquid crystal molecules are defined. The wall structure **215** also acts to define the directions of tilt of liquid crystal molecules during voltage application (during generation of an electric field) with its slope face effect. The alignment regulating force with the slope faces of the wall structure **115** acts even during non-voltage application, causing liquid crystal molecules to tilt. During voltage application, the inclined electric field with the cuts **213** and the action of an electric field distorted with the wall structure **215** define the directions of tilt of liquid crystal molecules, resulting in formation of the axisymmetric alignment as described above.

In the illustrated example, a total of four cuts **213** are given point-symmetrically with respect to the opening **214** corresponding to the center axis of a liquid crystal domain formed in the transmission region of the pixel (in this case, the right opening in the transmission region as viewed from FIG. **2**A).

By providing the cuts **213** as described above, the directions in which liquid crystal molecules fall during voltage application are defined, allowing formation of three liquid crystal domains. The placement and preferred shapes of the wall structure **215**, the openings **214** and the cuts **213** are the same as those described above in relation to the transmissive LCD device **100**. In the example illustrated in FIGS. **2**A and **2**B, the transmission region A has two liquid crystal domains and the reflection region B has one liquid crystal domain. However, the arrangement is not limited to this. Each liquid crystal domain is preferably roughly square in shape from the standpoint of the viewing angle characteristics and the stability of alignment.

Each of the shading conductive layers **216***a* is formed to cover a region including two opposing sides of the two cuts **213** opposed each other. In formation of the cuts **213** by etching, overetching, peeling off of a conductive film (an ITO film in the illustrated example) constituting the pixel electrode **211** and the like may occur and, as a result, the conductive film constituting the pixel electrode **211** may be cut off. Even in such a case, electrical connection can be secured with the shading conductive layer **116***a,* and thus formation of a region shut off from supply of a predetermined voltage in the pixel is prevented. Hence, it is possible to prevent/suppress occurrence of a display defect due to cutting off (disconnection) of the pixel electrode **211**. The shading conductive layers **216***a* (and the shading conductive layers **216***b*) may preferably be formed from the same layer as that for formation of the reflective electrode **211***b* at one time in the same step. This can suppress increase of the fabrication steps. Preferred examples of the material for forming the reflective electrode **211***b* and the shading conductive layers **216***a* and **216***b* include materials free from causing galvanic corrosion with the ITO layer constituting the transparent electrode **211***a* (for example, Ag, Ti, Ta, Mo, W, alloys thereof, and alloys of any of these materials and Al), and layered structures having any of the materials free from galvanic corrosion as an underlying layer (for example, structures having an Al layer on any of the above metal layers). Otherwise, a transparent electrode formed of a transparent conductive material less likely to cause galvanic corrosion with Al, such as IZO (InZnO) and ATO (SbSnO) may be used.

Al, Ag, Ti, Ta, Mo, W and alloys thereof can be used suitably because films thereof can be formed comparatively easily in a vacuum film formation process for electronic devices such as semiconductors and LCD devices, and also are suited for patterning by photolithography. Moreover, in transflective LCD devices, the shading conductive layers covering the cuts and the openings can be formed with the same material in the same film formation process as the reflective electrode film, and patterned into desired shapes by photolithography to be formed at predetermined positions. Therefore, with the formation of the shading conductive layers in the film formation process for the reflective electrodes, it is possible to shorten the process and improve the yield and thus reduce the fabrication cost.

The openings **214** are formed to fix the center axes of the axisymmetrically aligned domains. With the openings **214** formed in the pixel electrode **211**, depressions are formed on the surfaces of the shading conductive layers **216***b* covering the openings **214**. With the effect of the shape of the depressions, the directions of tilt of liquid crystal molecules are defined and the center axes of the axisymmetric alignment are fixed/stabilized. The shape of the openings **214** for formation of the depressions for fixing the center axes of the axisymmetrically aligned domains is preferably elliptic or circular as illustrated, but not limited to this. To exert roughly equal alignment regulating force in all directions, the shape is preferably a polygon having four or more sides and more preferably a regular polygon.

The shading conductive layers **216***b* covering the openings **214** act to suppress light leakage from near the center axes of the axisymmetric alignment formed in about the center of the liquid crystal domains. As described above, liquid crystal molecules near the alignment regulating structures are inclined more greatly (closer to the horizon) than liquid crystal molecules in the other regions. Regions having such alignment regulating structures are therefore observed as brighter than the other regions in the normally black display. In particular, the physical alignment regulating structures exert their alignment regulating force even during non-voltage application. This causes light leakage even in the black display state and resultantly reduces the contrast ratio. The depressions on the surfaces of the shading conductive layers **216***b* formed with the openings **214** define the directions of tilt of liquid crystal molecules with their shape effect. In addition, each of the openings **214**, formed for fixing the center axis of the axisymmetric alignment of the liquid crystal domain, is located in about the center of the sub-pixel. If light leakage occurs near the opening **214**, therefore, reduction in contrast ratio is eminent. By providing the shading conductive layer **216***b* to cover the opening **214**, the reduction in contrast ratio can be suppressed. Each of the shading conductive layers **216***a* formed to cover part of the cuts **213** also acts to suppress light leakage near the cuts **213**. However, to ensure sufficient exertion of the effect of the inclined electric field with the cuts **213**, it is not preferred to cover a wide area of the cuts **213** with the shading conductive layers **216***a,* but is preferred to form the shading conductive layers **216***a* to selectively cover only part of the cuts **213** for prevention of occurrence of disconnection in the pixel electrode **211**. The shading conductive layer **216***a* does not necessarily overlap part of the cuts **213**, but may only be formed on a portion in which a crack is likely to occur (in the illustrated example, a portion between the two opposing sides of the two cuts **213**) as described above.

The LCD device **200** has a shading region between the adjacent pixels, and the wall structure **215** extends on the transparent substrate **210***a* in the shading region. Since the shading region does not contribute to display, the wall structure **215** formed in the shading region is free from adversely affecting the display. The wall structure **215** shown in the illustrated example is a continuous wall surrounding the pixel. Alternatively, the wall structure **215** may be composed of a plurality of separate walls. The wall structure **215**, which serves to define boundaries of liquid crystal domains located near the outer edges of the pixel, should preferably have a length of some extent. For example, when the wall structure **215** is composed of a plurality of walls, each wall is preferably longer than the gap between the adjacent walls.

Supports **233** for defining the thickness of the liquid crystal layer **220** (also called the cell gap) should preferably be formed in the shading region (in the illustrated example, the region defined by the black matrix **232**) to avoid degradation of the display quality due to the supports. Although the supports **233** are formed on the wall structure **215** provided in the shading region in the illustrated example, the supports **233** may be formed on either transparent substrate **210***a* or **210***b*. In the case of forming the supports **233** on the wall structure **215**, setting is made so that the sum of the height of the wall structure **215** and the height of the supports **233** is equal to the thickness of the liquid crystal layer **220**. If the supports **233** are formed in a region having no wall structure **215**, setting is made so that the height of the supports **233** is equal to the thickness of the liquid crystal layer **220**.

In the LCD device **200**, when a predetermined voltage (voltage equal to or higher than a threshold voltage) is applied between the pixel electrode **211** and the counter electrode **231**, three axisymmetrically aligned domains are formed with the center axes thereof being stabilized in or near the three openings **214**. The four cuts **213** provided in the pixel electrode **211** define the directions in which liquid crystal molecules in the three adjacent liquid crystal domains fall with an electric field. The wall structure **214** stabilizes the boundaries of the liquid crystal domains located near the outer edges of the pixel.

In the LCD device **200** shown in FIGS. **2**A and **2**B, the alignment regulating structures such as the cuts **213**, the openings **214** and the wall structure **215** were placed only on the transparent substrate **210***a*. Alternatively, the alignment regulating structures may be formed on the transparent substrate **210***b*, or they may be formed on both the transparent substrates. Placing the alignment regulating structures only on either one substrate has the advantage of simplifying the fabrication process. Placing openings for center fixing on both substrates has the advantage of further effectively fixing/stabilizing the center axis of the axisymmetric alignment, and thus reducing the display roughness and shortening the response time in grayscale display.

The wall structure **215**, exerting its alignment regulating force even during non-voltage application, has the advantage of effectively stabilizing the axisymmetric alignment in a grayscale display state, but may be omitted depending on the use of the LCD device. The openings **214**, which serve to fix/stabilize the center axis of the axisymmetric alignment, provide the effect of improving the uniformity of the display, but may be omitted depending on the use of the LCD device.

Next, a preferred construction specific to the transflective LCD device **200** permitting both the transmission-mode display and the reflection-mode display will be described.

While light used for display passes through the liquid crystal layer **220** once in the transmission-mode display, it passes through the liquid crystal layer **220** twice in the reflection-mode display. Accordingly, as diagrammatically shown in FIG. **2**B, the thickness dt of the liquid crystal layer **220** in the transmission region A is preferably set roughly double the thickness dr of the liquid crystal layer **220** in the reflection region B. By setting in this way, the retardation given to the light by the liquid crystal layer **220** can be roughly the same in both display modes. Most preferably, $dr=0.5\ dt$ should be satisfied, but good display is secured in both display modes as long as $0.3\ dt<dr<0.7\ dt$ is satisfied. Naturally, $dt=dr$ may be satisfied depending on the use.

In the LCD device **200**, a transparent dielectric layer **234** is provided on the glass substrate **210***b* only in the reflection region B to make the thickness of the liquid crystal layer **220** in the reflection region B smaller than that in the transmission region A. This construction eliminates the necessity of providing a step by forming an insulating film and the like under the reflective electrode **211***b*, and thus has the advantage of simplifying the fabrication of the active matrix substrate **210***a*. If the reflective electrode **211***b* is formed on such an insulting film provided to give a step for adjusting the thickness of the liquid crystal layer **220**, light used for transmission display will be shaded with the reflective electrode covering a slope (tapered face) of the insulating film, or light reflected from the reflective electrode formed on a slope of the insulating film will repeat internal reflection, failing to be effectively used even for reflection display. By adopting the construction described above, occurrence of such problems is prevented, and thus the light use efficiency can be improved.

If the transparent dielectric layer **234** is provided with a function of scattering light (diffuse reflection function), white display close to good paper white can be realized without the necessity of providing the reflective electrode **211***b* with the diffuse reflection function. Such white display close to paper white can also be realized by making the surface of the reflective electrode **211***b* uneven, and in this case, no light scattering function is necessary for the transparent dielectric layer **234**. However, the uneven surface may fail to stabilize the position of the center axis of the axisymmetric alignment depending on the shape of the uneven surface. On the contrary, by combining the transparent dielectric layer **234** having the light scattering function and the reflective electrode **211***b* having a flat surface, the position of the center axis can be stabilized with the opening **214** (the depressions of the shading conductive layer **216***b*) formed in the reflective electrode **211***b* more reliably. Note that in the case of making the surface of the reflective electrode **211***b* uneven to provide the reflective electrode **211***b* with the diffuse reflection function, the uneven shape is preferably a continuous wave shape to prevent occurrence of an interference color, and such a shape is preferably set to allow stabilization of the center axis of the axisymmetric alignment.

While light used for display passes through the color filter layer **230** once in the transmission mode, it passes through the color filter layer **230** twice in the reflection mode. Accordingly, if the color filter layer **230** has the same optical density both in the transmission region A and the reflection region B, the color purity and/or the luminance may decrease in the reflection mode. To suppress occurrence of this problem, the optical density of the color filter layer in the reflection region is preferably made lower than that in the transmission region. The optical density as used herein is a characteristic value characterizing the color filter layer. For example, the optical density can be reduced by reducing the thickness of the color filter layer. Otherwise, the optical density can be reduced by reducing the density of a pigment added, for example, while keeping the thickness of the color filter layer unchanged.

Next, referring to FIGS. **3** and **4**, an example of the structure of an active matrix substrate suitably used for the transflective LCD device will be described. FIG. **3** is a partial enlarged view of the active matrix substrate, and FIG. **4** is a cross-sectional view taken along line X-X' in FIG. **3**. The active matrix substrate shown in FIGS. **3** and **4** can be the same in construction as the active matrix substrate **211***a* shown in FIGS. **2**A and **2**B, except that one liquid crystal domain is formed in the transmission region A (that is, the numbers of the openings **214** and the cuts **213** are reduced).

The active matrix substrate shown in FIGS. **3** and **4** has a transparent substrate **1** made of a glass substrate, for example. Gate signal lines **2** and source signal lines **3** run on the transparent substrate **1** to cross each other at right angles. TFTs **4** are formed near the crossings of these signal lines **2** and **3**. Drain electrodes **5** of the TFTs **4** are connected to corresponding pixel electrodes **6**.

Each of the pixel electrode **6** includes a transparent electrode **7** made of a transparent conductive layer such as an ITO layer and a reflective electrode **8** made of Al and the like. The transparent electrode **7** defines a transmission region A, and the reflective electrode **8** defines a reflection region B. Cuts **14** and openings **15** are formed at predetermined positions of the pixel electrode **6** for controlling the alignment of the axisymmetrically aligned domains as described above. Also, a shading conductive layer **216***a* is formed to cover two opposing sides of the two cuts **14** opposed each other, for prevention of occurrence of a display defect that may occur due to peeling off of a transparent conductive layer near the cuts **14**. The shading conductive layer **216***a* is formed integrally with the reflective electrode **8**. Also, a shading conductive layer **216***b* is formed to cover the opening **15***a* formed in the transparent electrode **7**, for suppression/prevention of reduction in contrast ratio due to light leakage from near the opening **15***a*. No shading conductive layer is provided for covering the opening **15***b* formed in the reflective electrode **8**. The opening **15***b* therefore defines the directions of tilt of liquid crystal molecules by generating an inclined electric field during voltage application, in addition to providing the effect of its concave shape. Hence, the effect of fixing/stabilizing the center axis of the axisymmetric alignment is higher in this case than the case of providing the shading conductive layer on the opening **15***b*. Although light leakage occurs near the opening **15***b*, it affects the contrast ratio less in the reflection region than in the transmission region. In view of the above, omitting the shading conductive layer to obtain greater alignment regulating force is more advantageous in some cases. Naturally, the shading conductive layer may be formed to cover the opening **15***b* if importance is attached to the contrast ratio.

A wall structure (not shown) is also placed in the non-display region (shading region) in which signal lines extend, outside the pixels in the above LCD device, for further stabilizing the axisymmetric domains.

The pixel electrode **6** overlaps the gate signal line for the next row via a gate insulating film **9**, forming a storage capacitance. The TFT **4** has a multilayer structure including the gate insulating film **9**, a semiconductor layer **12**, a channel protection layer **13** and an $n^+$-Si layer **11** (source/drain electrodes) formed in this order on a gate electrode **10** branched from the gate signal line **2**.

The illustrated TFT is of a bottom gate type. The TFT is not limited to this type, but a top gate type TFT can also be used.

(Operation principle)

The reason why the LCD device having a vertically aligned liquid crystal layer in the first aspect of the present invention has excellent wide viewing angle characteristics will be described with reference to FIGS. **5**A, **5**B, **6**A and **6**B.

FIGS. **5**A and **5**B are views for demonstrating how the alignment regulating force of a cut **13** (or an opening that is not covered with a shading conductive layer (for example, the opening **15***b* in FIG. **3**)) formed in a pixel electrode **6** acts, in which the aligned states of liquid crystal molecules during non-voltage application (FIG. **5**A) and during voltage application (FIG. **5**B) are diagrammatically shown. The state shown in FIG. **5**B is for display of a grayscale level.

The LCD device shown in FIGS. **5**A and **5**B includes an insulating film **16**, the pixel electrode **6** having the cuts **13** and an alignment film **12** formed in this order on a transparent substrate **1**. The LCD device also includes a color filter layer **18**, a counter electrode **19** and an alignment film **32** formed in this order on another transparent substrate **17**. A liquid crystal layer **20** interposed between the two substrates includes liquid crystal molecules **21** having negative dielectric anisotropy.

As shown in FIG. **5**A, during non-voltage application, the liquid crystal molecules **21** are aligned roughly vertical to the substrate surface with the alignment regulating force of the vertical alignment films **12** and **32**, and are aligned axisymmetrically around the concave portion of each cut **13** in or near the cut **13** with the effect of its concave shape.

As shown in FIG. **5**B, during voltage application, the liquid crystal molecules **21** having negative dielectric anisotropy attempt to make their major axes vertical to electric lines of force, and this causes the directions in which the liquid crystal molecules **21** fall to be defined with an inclined electric field generated around each cut **13**. In this way, the liquid crystal molecules **21** are aligned axisymmetrically around the cut **13** as the center. In the resultant axisymmetrically aligned domain, liquid crystal directors point in all directions (directions in the substrate plane), and thus, excellent viewing angle characteristics can be obtained. The alignment of liquid crystal molecules around the center axis is continuous.

When a wall structure is provided in addition to the cuts **13** and/or openings, the side (wall) face of the wall structure defines the directions in which the liquid crystal molecules **21** fall with the alignment regulating force. Since the wall structure is typically covered with a vertical alignment film, the alignment regulating force exerts to align the liquid crystal molecules vertical to the wall face.

FIGS. **6**A and **6**B are views for demonstrating the action of the alignment regulating force observed when a shading conductive layer **26** is formed to cover each opening **15** in the pixel electrode **6**. FIG. **6**A shows the construction exemplified in the embodiment described above. In FIG. **6**B, depressions **16***a* are formed on an underlying insulating layer **16** at the positions under the openings **15**. Both FIGS. **6**A and **6**B diagrammatically show the aligned state of the liquid crystal molecules during non-voltage application.

The aligned state of liquid crystal molecules shown in FIG. **6**A is substantially the same as that shown in FIG. **5**A. That is, the alignment direction of liquid crystal molecules is defined by the effect of the shape of the depressions formed by the openings **15**. However, in FIG. **6**A, no inclined electric field is generated near the openings **15** during voltage application. Therefore, as the liquid crystal molecules defined by the initial alignment with the depressions tilt with the electric field, liquid crystal molecules surrounding the liquid crystal molecules defined with the depressions start to be aligned to match with the liquid crystal molecules defined with the depressions, resulting in formation of axisymmetric alignment. Since the openings **15** are covered with the shading conductive layers **26**, the alignment regulating force is weak with no formation of an inclined electric field, but light leakage near the openings **15** is suppressed.

When the depressions (steps) obtained with the openings **15** are too shallow to provide sufficient alignment regulating force, depressions **16***a* may be formed on the underlying insulating layer **16** at the positions under the openings **15** as shown in FIG. **6**B, to increase the steps of the depressions formed thereon. As described above, the depth of the depressions **16***a* of the insulating layer **16** may be determined so that a step of preferably 0.1 μm or more, more preferably 0.15 μm or more, is formed on the surface facing the liquid crystal layer, to ensure the sufficient effect of fixing/stabilizing the center axis of the axisymmetric alignment on the surface. On the insulating layer (a resin layer having a thickness of 3 μm, for example) **16**, the pixel electrode (an ITO layer having a thickness of 150 nm, for example) **6**, the shading conductive layer (an Al layer having a thickness of 200 nm, for example) **26** and an alignment film (a vertical alignment film having a thickness of 80 nm, for example) **12**. In consideration of the above, the depth of the depression **16***a* is preferably 0.5 μm or more. If a depression having a depth exceeding 2 μm is formed on the surface contacting the liquid crystal layer, light leakage will disadvantageously increase because liquid crystal molecules tilt near the side faces of the depression.

Next, an example of more specific construction of the LCD device according to the present invention will be described with reference to FIG. **7**.

The LCD device shown in FIG. **7** includes: a backlight; a transflective liquid crystal panel **50**; a pair of polarizing plates **40** and **43** placed to face each other via the transflective liquid crystal panel **50**; quarter wave plates **41** and **44** respectively placed between the polarizing plates **40** and **43** and the liquid crystal panel **50**; and phase plates **42** and **45** having negative optical anisotropy respectively placed between the wave plates **41** and **44** and the liquid crystal panel **50**. The liquid crystal panel **50** includes a vertically aligned liquid crystal layer **20** between a transparent substrate (active matrix substrate) **1** and a transparent substrate (counter substrate) **17**. As the liquid crystal panel **50**, one having the same construction as that of the LCD device **200** shown in FIGS. **2**A and **2**B is used.

The display operation of the LCD device shown in FIG. **7** will be briefly described.

In reflection-mode display, light incident from above passes through the polarizing plate **43** to be output as linearly polarized light. The linearly polarized light is changed to circularly polarized light with the quarter wave plate **44** placed so that the slower axis thereof forms 45° with the transmission axis of the polarizing plate **43**. The circularly polarized light passes through the color filter layer (not shown) formed on the substrate **17**. In the illustrated example, the phase plate **45** provides no phase difference for light incident in the normal direction.

During non-voltage application, in which liquid crystal molecules in the liquid crystal layer **20** are aligned roughly vertical to the substrate plane, incident light passes through the liquid crystal layer **20** with a phase difference of roughly 0 and is reflected with the reflective electrode formed on the lower substrate **1**. The reflected circularly polarized light passes again through the liquid crystal layer **20** and the color filter layer. The light then passes through the phase plate **45** having negative optical anisotropy as the circularly polarized light, to enter the quarter wave plate **44**, where the light is changed to linearly polarized light having a polarizing direction orthogonal to the polarizing direction given to the incident light after first passing through the polarizing plate **43**, and reaches the polarizing plate **43**. The resultant linearly polarized light fails to pass through the polarizing plate **43**, and thus black display is provided.

During voltage application, in which the liquid crystal molecules in the liquid crystal layer **20** are tilted toward the horizontal direction from the direction vertical to the substrate plane, the incident circularly polarized light is changed to elliptically polarized light due to birefringence of the liquid crystal layer **20**, and reflected with the reflective electrode formed on the lower substrate **1**. The polarized state of the reflected light is further changed during passing back through the liquid crystal layer **20**. The reflected light passes again through the color filter layer and then the phase plate **45** having negative optical anisotropy, to enter the quarter wave plate **44** as the elliptically polarized light. Accordingly, when reaching the polarizing plate **43**, the light is not linearly polarized light having a polarizing direction orthogonal to the polarizing direction given to the original incident light, and thus passes through the polarizing plate **43**. That is to say, by adjusting the applied voltage, the degree of the tilt of the liquid crystal molecules can be controlled, and thus the amount of reflected light allowed to pass through the polarizing plate **43** can be changed, to thereby enable grayscale display.

In transmission-mode display, the upper and lower polarizing plates **43** and **40** are placed so that the transmission axes thereof are orthogonal to each other. Light emitted from a light source is changed to linearly polarized light at the polarizing plate **40**, and then changed to circularly polarized light when being incident on the quarter wave plate **41** placed so that the slower axis thereof forms 45° with the transmission axis of the polarizing plate **40**. The circularly polarized light then passes through the phase plate **42** having negative optical anisotropy and is incident on the transmission region A of the lower substrate **1**. In the illustrated example, the phase plate **42** provides no phase difference for light incident in the normal direction.

During non-voltage application, in which liquid crystal molecules in the liquid crystal layer **20** are aligned roughly vertical to the substrate plane, the incident light passes through the liquid crystal layer **20** with a phase difference of roughly 0. That is, the light incident on the lower substrate **1** as circularly polarized light passes through the liquid crystal layer **20** and then the upper substrate **17** in this state. The light then passes through the upper phase plate **45** having negative optical anisotropy, to enter the quarter wave plate **44**. The lower and upper quarter wave plates **41** and **44** are placed so that the slower axes thereof are orthogonal to each other. Therefore, a phase difference in the polarized light that has entered the quarter wave plate **44**, which was given at the lower quarter wave plate **41**, can be cancelled with the quarter wave plate **44**, and thus the light resumes the, original linearly polarized light. The polarized light coming from the upper quarter wave plate **44** is therefore linearly polarized light having the polarizing direction parallel with the transmission axis (polarizing axis) of the polarizing plate **40**, and thus absorbed with the polarizing plate **43** of which the transmission axis is orthogonal to that of the polarizing plate **40**. Accordingly, black display is provided.

During voltage application, in which the liquid crystal molecules in the liquid crystal layer **20** are tilted toward the horizontal direction from the direction vertical to the substrate plane, the incident circularly polarized light is changed to elliptically polarized light due to birefringence of the liquid crystal layer **20**. The light then passes through the color filter layer **17**, the phase plate **45** having negative optical anisotropy, and the quarter wave plate **44** as the elliptically polarized light. Accordingly, when reaching the polarizing plate **43**, the light is not linearly polarized light orthogonal to the polarized component in the original incident light, and thus passes through the polarizing plate **43**. That is to say, by adjusting the applied voltage, the degree of the tilt of the liquid crystal molecules can be controlled, and thus the amount of light allowed to pass through the polarizing plate **43** can be changed, to thereby enable grayscale display.

The phase plate having negative optical anisotropy minimizes the amount of change in phase difference occurring with change of the viewing angle when the liquid crystal molecules are in the vertically aligned state, and thus suppresses black floating observed when the display device is viewed at a wide viewing angle. In place of the combination of the phase plate having negative optical anisotropy and the quarter wave plate, a biaxial phase plate unifying the functions of both plates may be used.

When axisymmetrically aligned domains are used to implement the normally black mode that presents black display during non-voltage application and white display during voltage application, as in the present invention, a polarizing plate-caused extinction pattern can be eliminated by placing a pair of quarter wave plates on the top and bottom of the LCD device (panel), and thus the brightness can be improved. Also, when axisymmetrically aligned domains are used to implement the normally black mode with upper and lower polarizing plates placed so that the transmission axes thereof are orthogonal to each other, it is theoretically possible to present black display of substantially the same level as that obtained when a pair of polarizing plates are placed under crossed nicols. Therefore, a considerably high contrast ratio can be obtained, and also, with the all-direction alignment of liquid crystal molecules, wide viewing angle characteristics can be attained.

The thicknesses dt and dr of the liquid crystal layer in the transmission region and the reflection region defined in the present invention preferably has the relationship satisfying 0.3 dt<dr<0.7 dt, more preferably 0.4 dt<dr<0.6 dt, as is found from the dependence of the voltage-reflectance (transmittance) of the transmission region and the reflection region on the thickness of the liquid crystal layer shown in FIG. **8**. If the thickness of the liquid crystal layer in the reflection region is smaller than the lower limit, the reflectance will be 50% or less of the maximum reflectance, failing to provide sufficiently high reflectance. If the thickness dr of the liquid crystal layer in the reflection region is greater than the upper limit, the peak of the reflectance in the voltage-reflectance characteristics exists at a drive voltage different from that in the case of the transmission display. Also, the relative reflectance tends to be low at a white display voltage optimal for the transmission display. The reflectance is as low as 50% or less of the maximum reflectance, failing to provide sufficiently high reflectance. Since the optical length in the liquid crystal layer in the reflection region B is double that in the transmission region, the birefringence anisotropy (Δn) of the liquid crystal material and the panel cell thickness design are very important when the same design is made for both the transmission region and the reflection region.

Specific characteristics of the transflective LCD device of the embodiment of the present invention will be described as follows.

An LCD device having the construction shown in FIG. **7** was fabricated. As the liquid crystal cell **50**, one having the same construction as that of the LCD device **200** shown in FIGS. **2**A and **2**B was used. A transparent dielectric, layer having no light scattering function was formed as the transparent dielectric layer **234**, and a resin layer having a continuous uneven surface was formed under the reflective electrode **211***b*, to adjust the diffuse reflection characteristics in the reflection display.

In the example, a pair of cuts were formed near the boundary between the transmission region and the reflection region, to control the tilt alignment of liquid crystal molecules using a distortion of an electric field. Also, an opening was formed in an electrode roughly in the center of a liquid crystal domain in the pixel region, to fix/stabilize the position of the center axis of the axisymmetric alignment. In addition, a wall structure was formed in the shading region outside the pixel region so as to regulate the directions of tilt of liquid crystal molecules from the periphery of the pixel. According to the first aspect of the present invention, the same Al film as that used as the reflective electrode film in the reflection region was formed to cover a region near the pair of cuts and also the opening formed roughly in the center of a liquid crystal domain in the pixel, in the same vacuum film formation process, and patterned in a predetermined photographic process. As a result, occurrence of a display defect due to peeling off of a pixel electrode film near the cuts was prevented. Also, reduction in contrast due to alignment disorder near the step of the opening in the center of the pixel during black display was suppressed with the shading effect using the metal conductive film.

In the LCD device of the above example, the vertical alignment films were formed by a known method. No rubbing was made. A liquid crystal material having negative dielectric anisotropy (Δn: 0.1 and Δ∈: −4.5) was used. In this example, the thicknesses dt and dr of the liquid crystal layer in the transmission region and the reflection region were set at 4 μm and 2.2 μm, respectively (dr=0.55 dt).

The LCD device of this example had a multilayer structure composed of a polarizing plate (observer side), a quarter wave plate (phase plate **1**), a phase plate having negative optical anisotropy (phase plate **2** (NR plate)), the liquid crystal layer (on the upper and lower sides thereof, the color filter substrate and the active matrix substrate were respectively placed), a phase plate having negative optical anisotropy (phase plate **3** (NR plate)), a quarter wave plate (phase plate **4**), and a polarizing plate (backlight side) in the order from the observer side. The upper and lower quarter wave plates (phase plates **1** and **4**) were placed so that the slower axes thereof were orthogonal to each other, and had a phase difference of 140 nm. The phase plates having negative optical anisotropy (phase plates **2** and **3**) had a phase difference of 135 nm. The two polarizing plates were placed so that the absorption axes thereof were orthogonal to each other.

A drive signal was applied to the thus-obtained LCD device (4V was applied across the liquid crystal layer) to evaluate the display characteristics. No black point or the like accompanying a display defect of a pixel was recognized in full-lighting inspection of the LCD device. The results of the visual angle—contrast characteristics in the transmission display are shown in FIG. **9**. The viewing angle characteristics in the transmission display were roughly symmetric in all directions, the range CR>10 was as large as up to ±80°, and the transmission contrast was as high as 300:1 or more at the front.

As for the characteristics of the reflection display, the reflectance evaluated with a spectral calorimeter (CM2002 from Minolta Co., Ltd.) was about 8.7% (value in terms of the aperture ratio of 100%) with respect to a standard diffuse plate as the reference. The contrast value of the reflection display was 23, which was high compared with the case of the conventional LCD devices.

As a comparative example, an LCD device having the openings, the cuts and the wall structure as those in the above example but having no shading conductive layer was fabricated. In full-lighting examination of this LCD device, black points (display defects) caused by peeling off of the pixel electrodes (transparent electrodes) were recognized. Moreover, in microscopic observation, light leakage near the depressions (steps) of the openings was observed, and reduction in contrast ratio due to the light leakage was recognized. In this comparative example, the contrast value in the transmission display during 4V voltage application was 280:1 at the front, which was slightly lower than that in the above example.

In the embodiment described above, vertically aligned LCD devices having axisymmetrically aligned liquid crystal domains were exemplified. Alternatively, the present invention is also applicable to MVA LCD devices.

[Transflective LCD Device having Transparent Dielectric Layer]

As described above, in the transflective LCD device, the thicknesses dt and dr of the liquid crystal layer in the transmission region and the reflection region are preferably set to satisfy the relationship 0.3 dt<dr<0.7 dt. Placing a transparent dielectric layer (thickness: dt−dr) on the surface of the counter substrate (typically, a color filter substrate) facing the liquid crystal layer eliminates the necessity of providing a step by forming an insulating film and the like under the reflective electrode, and thus has advantages such as simplifying the fabrication of the active matrix substrate **210***a*.

However, with the step formed by the transparent dielectric layer, the alignment of liquid crystal molecules in the pixel may be disturbed and this may make it difficult to form the axisymmetric alignment in each of the transmission region and the reflection region or control the center position of the axisymmetric alignment. As a result, display-related problems such as light leakage, visual angle dependence and roughness of display may arise.

Hereinafter, described will be a transflective LCD device of an embodiment according to the second aspect of the present invention that can suppress disturbance in the alignment of liquid crystal molecules caused by the step formed in the liquid crystal panel and thus can sufficiently stabilize the alignment of liquid crystal molecules and prevent occurrence of display failure. The LCD device according to the second aspect of the invention can be suitably combined with the transflective LCD device according to the first aspect of the invention described above.

A transflective LCD device **300** of an embodiment according to the second aspect of the present invention will be described with reference to FIGS. **10**A, **10**B and **11**.

FIGS. **10**A and **10**B diagrammatically show one pixel of the transflective LCD device **300** according to the second aspect of the present invention, in which FIG. **10**A is a plan view and FIG. **2**B is a cross-sectional view taken along line **10**B-**10**B' in FIG. **10**A. FIG. **11** is an enlarged view of the boundary between a reflection region and a transmission region in FIG. **10**B. The transflective LCD device **300** is different from the transflective LCD device **200** shown in FIGS. **2**A and **2**B in the point that the placement of a transparent dielectric layer **334** with respect to cuts **313***a* is optimized as will be described later. Although the illustrated transflective LCD device **300** is not provided with the wall structure **215**, the openings **214** and the shading conductive layers **216** of the transflective LCD device **200**, these components are preferably provided as described earlier in detail. Description of the common components between the transflective LCD devices **200** and **300** is omitted here.

The transflective LCD device **300** includes a transparent substrate **310***a*, a transparent substrate **310***b* placed to face the transparent substrate **310***a*, and a vertically aligned liquid crystal layer **320** interposed between the transparent substrates **310***a* and **310***b*.

The LCD device **300** further includes pixel electrodes **311** formed on the transparent substrate **310***a* and a counter electrode **331** formed on the transparent substrate **310***b*. Each pixel electrode **311**, the counter electrode **331** and the liquid crystal layer **320** interposed between these electrodes define a pixel. Circuit elements such as TFTs are formed on the transparent substrate **310***a*.

Typically, color filters **330** provided for the respective pixels, a black matrix (shading layer) **332** provided in the gaps between the adjacent color filters **330**, and the transparent dielectric layer **334** are formed on the surface of the transparent substrate **310***b* facing the liquid crystal layer **320**, and the counter electrode **331** is formed on these components.

Each pixel electrode **311** includes a transparent electrode **311***a* formed of a transparent conductive layer (for example, an ITO layer) and a reflective electrode **311***b* formed of a metal layer (for example, an Al layer, an alloy layer including Al, and a layered film including any of these). Having such a pixel electrode, each pixel includes a transmission region A defined by the transparent electrode **311***a* and a reflection region B defined by the reflective electrode **311***b*, to provide display in the transmission mode and display in the reflection mode, respectively.

While light used for display passes through the liquid crystal layer **320** once in the transmission-mode display, it passes through the liquid crystal layer **320** twice in the reflection-mode display. Accordingly, as diagrammatically shown in FIG. **10**B, the thickness dt of the liquid crystal layer **320** in the transmission region A is preferably set roughly double the thickness dr of the liquid crystal layer **320** in the reflection region B. By setting in this way, the retardation given to the light by the liquid crystal layer **320** can be roughly the same in both display modes. Most preferably, dr=0.5 dt should be satisfied, but good display is secured in both display modes as long as 0.3 dt<dr<0.7 dt is satisfied.

In the LCD device **300** shown in FIGS. **10**A and **10**B, in which the number of divided parts (=N) is 3 (two for the transmission region and one for the reflection region), four cuts **313** are formed at predetermined positions in the pixel electrode **311**. Two cuts **313***a* among the four cuts are formed between the transparent electrode **311***a* and the reflective electrode **311***b*. In the illustrated construction, the cuts **313***a* are located in the portion of the transparent electrode **311***a* adjacent to the reflective electrode **311***b*. The other two cuts **313***b* are located near the boundary of two axisymmetrically aligned domains formed in the transmission region A having the transparent electrode **311***a* (at the position roughly bisecting the transparent electrode **311***a* in the length direction). An inclined electric field is generated near the portions of the pixel electrode **311** having these four (two pairs of) cuts **313**, to enable formation of three axisymmetrically aligned domains in the pixel.

A step is formed with the transparent dielectric layer **334** formed in the reflection region B on the surface of the counter substrate **310***b* facing the liquid crystal layer **320**. The placement of the transparent dielectric layer **334** with respect to the cuts **313***a* is set so that the alignment of liquid crystal molecules near this step formed in the vicinity of the boundary between the transmission region A and the reflection region B (near the end face of the transparent dielectric layer **334**) matches with the alignment of liquid crystal molecules given with the inclined electric field generated near the cuts **313***a*.

The above setting will be described in detail with reference to FIG. **11**.

The transparent dielectric layer **334**, placed to set the thickness dr of the liquid crystal layer **320** in the reflection region B, exists in at least the region opposed to the reflective electrode **311***b*, and in general, is formed to be slightly greater in size than the reflective electrode **311***b* in consideration of obliquely-traveling light. Hence, the end face of the transparent dielectric layer **334** near the boundary between the transmission region A and the reflection region B (extension line EL in FIG. **11**) is located on the side of the transparent electrode **311***a*, not on the side of the reflective electrode **311***b*.

If the end face (EL) of the transparent dielectric layer **334** is located on the side of the transparent electrode **311***a* with respect to the center (extension line CL in FIG. **11**) of the width W of the cut **313***a*, the alignment of liquid crystal molecules near the boundary between the liquid crystal domain formed in the transmission region A and the liquid crystal domain formed in the reflection region B is disturbed, and this tends to make the axisymmetric alignment formed in the transmission region and the reflection region unstable.

Table 1 below shows the results of an experiment. In Table 1, dL denotes the distance between the end face (EL) of the transparent dielectric layer **334** and the center (CL) of the width W of the cut **313**_a_. The value of the distance is "positive" when the end face (EL) is on the side of the reflective electrode **311**_b_ with respect to the center (CL)(right as viewed from FIG. **11**).

In this example, a liquid crystal material having negative dielectric anisotropy (Δn: 0.1 and Δ∈: −4.5) was used. The thicknesses dt and dr of the liquid crystal layer in the transmission region and the reflection region were set at 4 μm and 2.2 μm, respectively (dr=0.55 dt). The length of the pixel electrode in the shorter-side (width) direction is 50 μm, the length thereof in the longer-side (length) direction is 160 μm, and the length of the cut (in the shorter-side direction of the pixel electrode) is 20 μm.

In Table 1, mark ○ represents that a total of three (two in the transmission region A and one in the reflection region B) axisymmetrically aligned domains were formed, and mark X represents that the three axisymmetrically aligned domains were not formed stably.

TABLE 1

| | | dL [μm] | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | −6 | −5 | −4 | −3 | −2 | −1 | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
| W [μm] | 2 | — | — | — | — | — | X | X | X | — | — | — | — | — |
| | 4 | — | — | — | — | X | X | X | X | X | — | — | — | — |
| | 6 | — | — | — | X | X | X | X | X | X | X | — | — | — |
| | 7 | — | — | — | X | X | X | ○ | ○ | ○ | ○ | — | — | — |
| | 8 | — | — | X | X | X | X | ○ | ○ | ○ | ○ | ○ | — | — |
| | 10 | — | X | X | X | X | X | ○ | ○ | ○ | ○ | ○ | ○ | — |
| | 12 | X | X | X | X | X | X | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

As is found from the results in Table 1, to give stable axisymmetric alignment, the end face (EL) of the transparent dielectric layer **334** should preferably coincide with the center (CL) of the width W of the cut **313**_a_ (dL=0) or be located on the side of the reflective electrode **311**_b_ with respect to the center (CL), and the width W of the cut should be 7 μm or more.

The effect of the width W of the cut on the alignment of liquid crystal molecules was examined, and the results are as follows.

FIGS. **12**A through **12**F are views diagrammatically showing liquid crystal molecules LC (line segments in the figures) and equipotential lines EQ of an electric field generated in a liquid crystal layer, observed 200 msec after application of a white voltage (4V in the illustrated example) across the liquid crystal layer. The thickness of the liquid crystal layer was 4 μm, the refractive index anisotropy Δn was 0.1 and the dielectric anisotropy Δ∈ was −4.5. Walls (wall structure or projections) were placed on the surface of the counter electrode facing the liquid crystal layer at intervals of 30 μm, but the action of these walls on the action of the cuts is negligible.

FIGS. **12**A to **12**F respectively show the cases that no cut is formed (FIG. **12**A), the width W of a cut is 3 μm (FIG. **12**B), 6 μm (FIG. **12**C), 9 μm (FIG. **12**D), 12 μm (FIG. **12**E) and 15 μm (FIG. **12**F). As is found from FIGS. **12**A through **12**F, as the width W of the cut increases, the equipotential lines EQ are more drawn into the cut, and with this, liquid crystal molecules in the cut are aligned closer to the vertical.

Why the width W of the cut of 7 μm was obtained from the results in Table 1 will be described.

The LCD device used for the experiment of which the results are shown in Table 1 has the voltage-transmittance characteristics (V-T curve) shown in FIG. **13** in which the threshold voltage of the liquid crystal layer is 1.6 V. The threshold voltage as used herein is defined as a voltage which gives 3% transmittance of the transmittance at a saturation voltage.

FIG. **14** is a graph showing the results of calculation of the relationship between the width W of a cut and the potential at the center (position of W/2) of the cut. As is found from FIG. **14**, as the width W of the cut increases, the potential at the center of the cut decreases. It is when the width W is about 7 μm that the potential is 1.6 V, the threshold voltage.

In other words, when the width W of the cut is greater than the width W with which the potential at the center of the cut is roughly equal to the threshold voltage, the axisymmetrically aligned domains can be formed stably by forming the transparent dielectric layer **334** so that the end face (EL) thereof coincides with the center (CL) of the width W of the cut **313**_a_ (dL=0) or is located on the side of the reflective electrode **311**_b_ with respect to the center (CL).

As described above, the width W of the cut is preferably 7 μm or more, but to suppress reduction in aperture ratio, a smaller width W of the cut is more preferable. It is therefore preferred to set the minimum center value so that the width W of the cuts of 7 μm or more is secured even in consideration of the process margin.

The reason why the axisymmetrically aligned domains are formed stably with the above construction will be described with reference to FIGS. **15**A and **15**B.

FIG. **15**A is a view diagrammatically showing equipotential lines EQ of an electric field generated near the cut **313**_a_ in the liquid crystal layer and the alignment of liquid crystal molecules LC in a liquid crystal display device of an embodiment of the present invention, and FIG. **15**B is a view diagrammatically showing equipotential lines EQ of an electric field generated in a liquid crystal layer and the alignment of liquid crystal molecules LC in the case of providing no cuts. The counter electrode (not shown) is formed covering the transparent dielectric layer. These are the results of alignment simulation obtained when a white voltage (4 V in the illustrated example) was applied between the electrodes.

As shown in FIG. **15**A, when the end face of the transparent dielectric layer **334** coincides with the end of reflective electrode **311**_b_ (the end facing the transparent electrode **311**_a_) (that is, dL=W/2), the alignment direction of liquid crystal molecules near the side face of the transparent dielectric layer **334** facing the transmission region matches with the alignment direction of liquid crystal molecules caused by the inclined electric field generated with the cut **313**_a_. As a result, the axisymmetric alignment is given stably in the reflection region and the transmission region.

On the contrary, as is found from FIG. **15**B, when no cut is formed, the alignment direction of liquid crystal molecules near the side face of the transparent dielectric layer conflicts with the alignment direction of liquid crystal molecules near the pixel electrode. As a result, no stable formation of axisymmetric alignment is attained.

To keep the alignment of liquid crystal molecules with the inclined electric field (alignment regulating force) generated with the cut **313**_a_ from being disturbed with the step of the transparent dielectric layer **334**, the end face (EL) of the transparent dielectric layer **334** should preferably coincide with the center (CL) of the width W of the cut **113**_a_ (dL=0) or be located on the side of the reflective electrode **311**_b_ with respect to the center (CL), as described above with reference to Table 1. Also, the width of the cut **313**_a_ is preferably set so that the potential at the center of the cut **313**_a_ is equal to or less than the threshold voltage of the liquid crystal layer when a white voltage is applied. This relationship is substantially established when 0.3 dt<dr<0.7 dt is satisfied.

As described above, according to the present invention, an LCD device with excellent display quality can be implemented with a comparatively simple construction. The present invention is suitably applied to transmissive LCD devices and transflective (transmissive/reflective) LCD devices. In particular, transflective LCD devices are suitably used as display devices for mobile equipment such as mobile phones.

While the present invention has been described with respect to preferred embodiments thereof, it will be apparent to those skilled in the art that the disclosed invention may be modified in numerous ways and may assume many embodiments other than those specifically described above. Accordingly, it is intended by the appended claims to cover all modifications of the invention that fall within the true spirit and scope of the invention.

This non-provisional application claims priority under 35 USC §119(a) on Patent Applications No. 2004-043537 filed in Japan on Feb. 19, 2004 and 2005-028649 filed in Japan on Feb. 4, 2005, the entire contents of which are hereby incorporated by reference.

What is claimed is:

**1**. A liquid crystal display device comprising a first substrate, a second substrate opposed to the first substrate, and a vertically aligned liquid crystal layer interposed between the first substrate and the second substrate,

wherein the liquid crystal display device has a plurality of pixels, each pixel including a first electrode formed on the first substrate, a second electrode formed on the second substrate, and the liquid crystal layer interposed between the first electrode and the second electrode,

the first electrode has at least one opening or cut formed at a predetermined position in the pixel,

at least one shading conductive layer electrically connected to the first electrode is formed at least near the at least one opening or cut,

in each of the plurality of pixels, a plurality of regions in which directions of tilt of liquid crystal molecules are different from one another are formed when at least a predetermined voltage is applied across the liquid crystal layer, and

wherein at least one shading conductive layer is surrounded on all lateral sides by the first electrode and is not located between adjacent pixels.

**2**. The device of claim **1**, wherein, in each of the plurality of pixels, at least one liquid crystal domain exhibiting axisymmetric alignment is formed when at least a predetermined voltage is applied across the liquid crystal layer.

**3**. The device of claim **1**, wherein the at least one shading conductive layer includes a shading conductive layer covering at least part of the at least one opening or cut.

**4**. The device of claim **1**, wherein the at least one opening or cut includes two cuts opposed each other, and the at least one shading conductive layer includes a first shading conductive layer covering the two opposing sides of the two cuts.

**5**. The device of claim **1**, wherein the at least one opening or cut includes at least two openings, and the at least one shading conductive layer includes at least two shading conductive layers covering the at least two openings.

**6**. The device of claim **5**, wherein the liquid crystal layer has at least two liquid crystal domains each exhibiting axisymmetric alignment when at least a predetermined voltage is applied, and the center axes of the axisymmetric alignment of the at least two liquid crystal domains are formed in or near the at least two openings.

**7**. The device of claim **1**, wherein the shading conductive layer is formed of a metal film.

**8**. The device of claim **7**, wherein the metal film includes at least one kind of metal element selected from the group consisting of Al, Ag, Ti, Ta, Mo and W.

**9**. The device of claim **1**, further comprising a shading region in the gaps between the plurality of pixels, and a wall structure regularly arranged on the surface of the first substrate facing the liquid crystal layer in the shading region.

**10**. The device of claim **1**, wherein the first electrode includes a transparent electrode defining a transmission region and a reflective electrode defining a reflection region, at least one liquid crystal domain includes a liquid crystal domain formed in the transmission region, the at least one opening or cut includes an opening corresponding to a center axis of the liquid crystal domain formed in the transmission region and a plurality of cuts formed point-symmetrically with respect to the opening.

**11**. The device of claim **1**, further comprising: a pair of polarizing plates placed to face each other via the first substrate and the second substrate; and at least one biaxial optical anisotropic medium layer placed between the first substrate and one of the pair of polarizing plates and/or between the second substrate and the other polarizing plate.

**12**. The device of claim **1**, further comprising: a pair of polarizing plates placed to face each other via the first substrate and the second substrate; and at least one uniaxial optical anisotropic medium layer placed between the first substrate and one of the pair of polarizing plates and/or between the second substrate and the other polarizing plate.

**13**. A liquid crystal display device comprising a first substrate, a second substrate opposed to the first substrate, and a vertically aligned liquid crystal layer interposed between the first substrate and the second substrate,

wherein the liquid crystal display device has a plurality of pixels, each pixel including a first electrode formed on the first substrate, a second electrode formed on the second substrate, and the liquid crystal layer interposed between the first electrode and the second electrode,

the first electrode has at least one opening or cut formed at a predetermined position in the pixel,

at least one shading conductive layer electrically connected to the first electrode is formed at least near the at least one opening or cut,

in each of the plurality of pixels, a plurality of regions in which directions of tilt of liquid crystal molecules are different from one another are formed when at least a predetermined voltage is applied across the liquid crystal layer;

wherein the second electrode has at least one further opening formed at a predetermined position in the pixel, and

a center axis of axisymmetric alignment of at least one liquid crystal domain formed when at least a predetermined voltage is applied across the liquid crystal layer is formed in or near the at least one further opening.

**14**. The device of claim **13**, wherein at least one further shading conductive layer electrically connected to the second electrode is formed to cover the at least one further opening.

**15**. The device of claim **14**, wherein the first electrode includes a transparent electrode defining a transmission region and a reflective electrode defining a reflection region, and a thickness dt of the liquid crystal layer in the transmission region and a thickness dr of the liquid crystal layer in the reflection region satisfy a relationship $0.3\ dt < dr < 0.7\ dt$.

**16**. The device of claim **15**, wherein the reflective electrode and the at least one shading conductive layer are formed from a same metal film.

**17**. The device of claim **15**, wherein a transparent dielectric layer is formed selectively on the second substrate in the reflection region.

**18**. A liquid crystal display device according to claim **17**, comprising a first substrate, a second substrate opposed to the first substrate, and a vertically aligned liquid crystal layer interposed between the first substrate and the second substrate,

wherein the liquid crystal display device has a plurality of pixels, each pixel including a first electrode formed on the first substrate, a second electrode formed on the second substrate, and the liquid crystal layer interposed between the first electrode and the second electrode,

the first electrode has a transparent electrode defining a transmission region, a reflective electrode defining a reflection region, and a cut formed between the transparent electrode and the reflective electrode,

the second substrate further has a transparent dielectric layer in the reflection region,

the thickness dt of the liquid crystal layer in the transmission region and the thickness dr of the liquid crystal layer in the reflection region satisfy the relationship 0.3 dt<dr<0.7 dt,

the transparent dielectric layer has an end face coinciding the center of the width of the cut or located on the side of the reflective electrode with respect to the center, and

the liquid crystal layer has at least one liquid crystal domain exhibiting axisymmetric alignment in each of the transmission region and the reflection region when at least a predetermined voltage is applied.

**19**. The device of claim **18**, wherein the potential at the center of the cut is lower than a threshold voltage of the liquid crystal layer when a white voltage is applied across the liquid crystal layer.

* * * * *

patsnap

| | | | |
|---|---|---|---|
| 专利名称(译) | 液晶显示装置，包括至少靠近电极的开口或切口形成的遮光导电层 | | |
| 公开(公告)号 | US7724326 | 公开(公告)日 | 2010-05-25 |
| 申请号 | US11/061601 | 申请日 | 2005-02-22 |
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摘要(译)

本发明的液晶显示装置具有多个像素，每个像素包括第一电极111，第二电极131和插入在第一和第二电极之间的垂直取向的液晶层120。第一电极具有形成在像素中的预定位置处的至少一个开口114或切口113。至少一个与第一电极电连接的遮光导电层116至少形成在至少一个开口或切口附近。在多个像素中的每个像素中，当在液晶层上施加至少预定电压时，形成多个区域，其中液晶分子的倾斜方向彼此不同。