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(54) **LIQUID CRYSTAL DISPLAY HAVING WIDE VIEWING ANGLE**

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

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Related U.S. Application Data

(60) Continuation of application No. 12/147,697, filed on Jun. 27, 2008, now Pat. No. 7,787,087, which is a division of application No. 11/398,839, filed on Apr. 6, 2006, now Pat. No. 7,787,086, which is a continuation of application No. 11/183,744, filed on Jul. 19, 2005, now Pat. No. 7,050,134, which is a continuation of application No. 10/861,397, filed on Jun. 7, 2004, now Pat. No. 6,937,311, which is a continuation of application No. 10/269,861, filed on Oct. 15, 2002, now Pat. No. 6,778,244, which is a continuation of application No. 10/020,303, filed on Dec. 18, 2001, now Pat. No. 6,512,568, which is a continuation of application No. 09/314,293, filed on May 19, 1999, now Pat. No. 6,342,938.

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G02F 1/1337 (2006.01)

(52) **U.S. Cl.** **349/129**; 349/130

(58) **Field of Classification Search** 349/129–130
See application file for complete search history.

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(57) **ABSTRACT**

A tetragonal ring shape aperture is formed in the common electrode on one substrate and a cross shape aperture is formed at the position corresponding to the center of the tetragonal ring shape aperture in the pixel electrode on the other substrate. A liquid crystal layer between two electrodes are divided to four domains where the directors of the liquid crystal layer have different angles when a voltage is applied to the electrodes. The directors in adjacent domains make a right angle. The tetragonal ring shape aperture is broken at midpoint of each side of the tetragon, and the width of the aperture decreases as goes from the bent point to the edge. Wide viewing angle is obtained by four domains where the directors of the liquid crystal layer indicate different directions, disclination is removed and luminance increases.

7 Claims, 12 Drawing Sheets

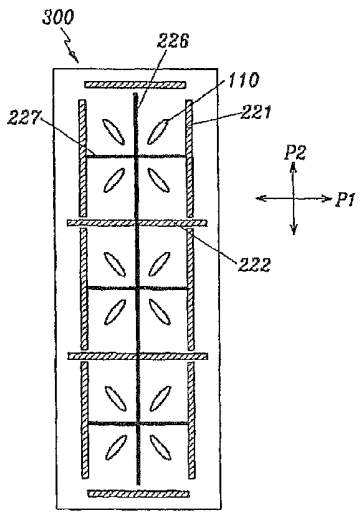

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FIG. 1A

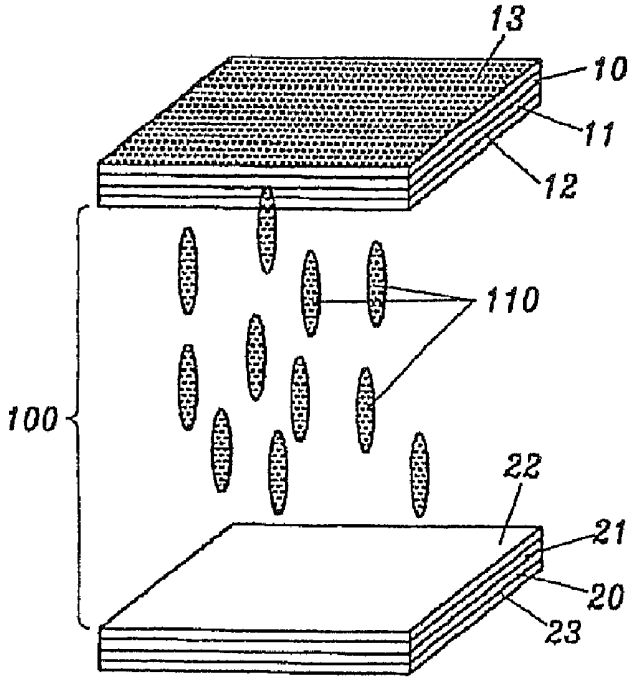


FIG. 1B

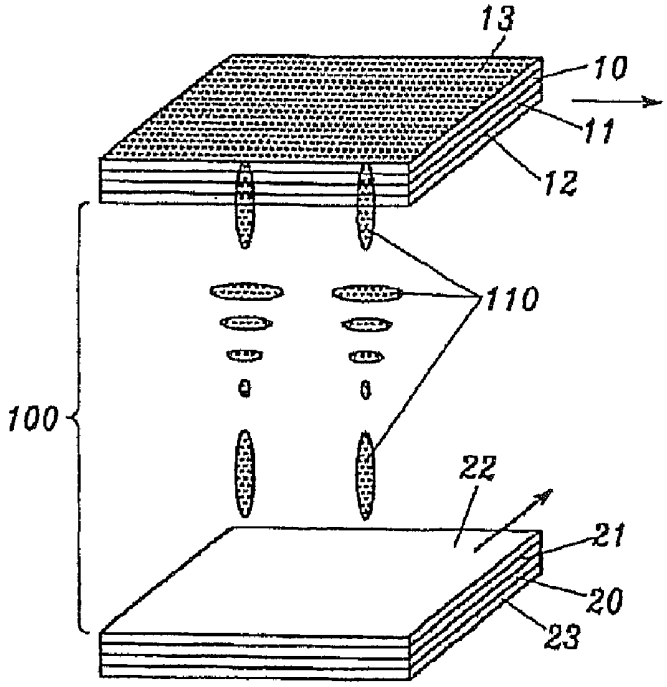
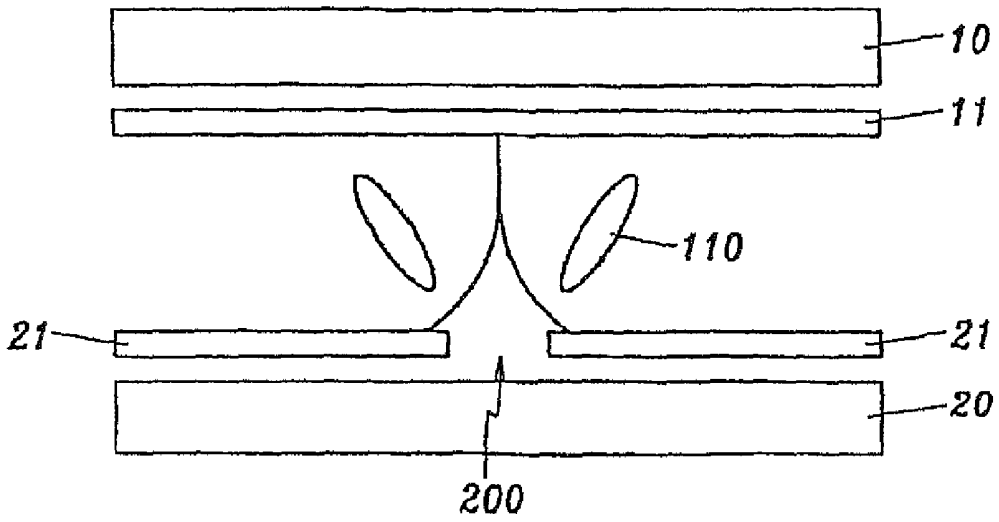


FIG. 2



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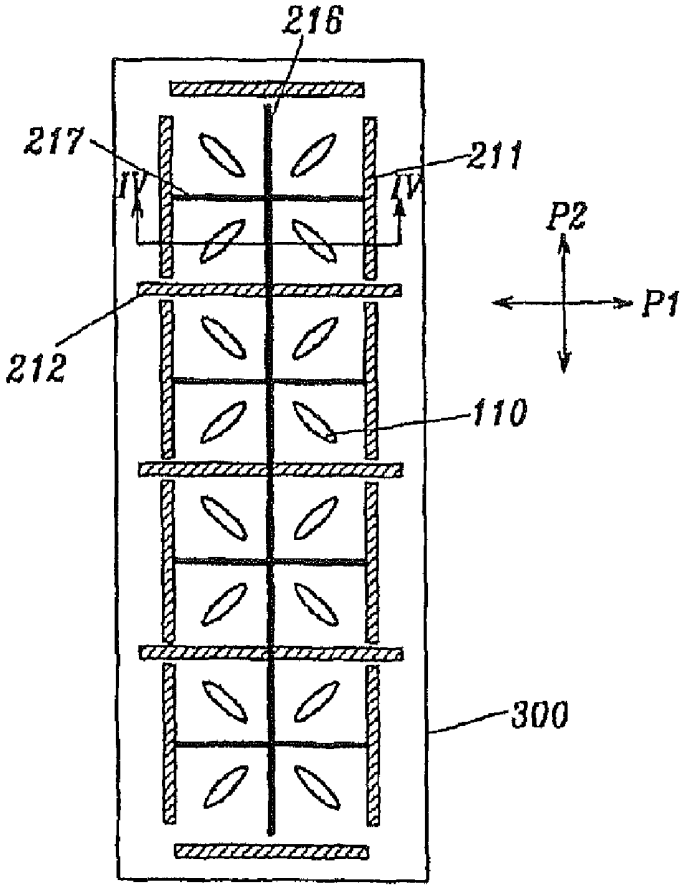

216
217
211
IV
IV
P2
P1
212
110
300

FIG. 4

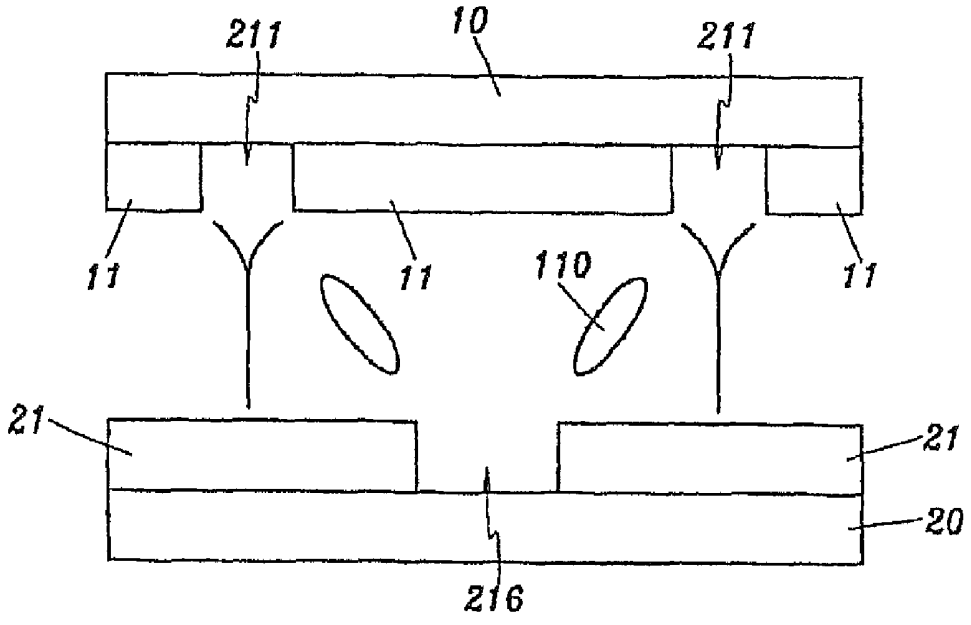

211
10
211
11
11
110
11
21
21
20
216

FIG. 5

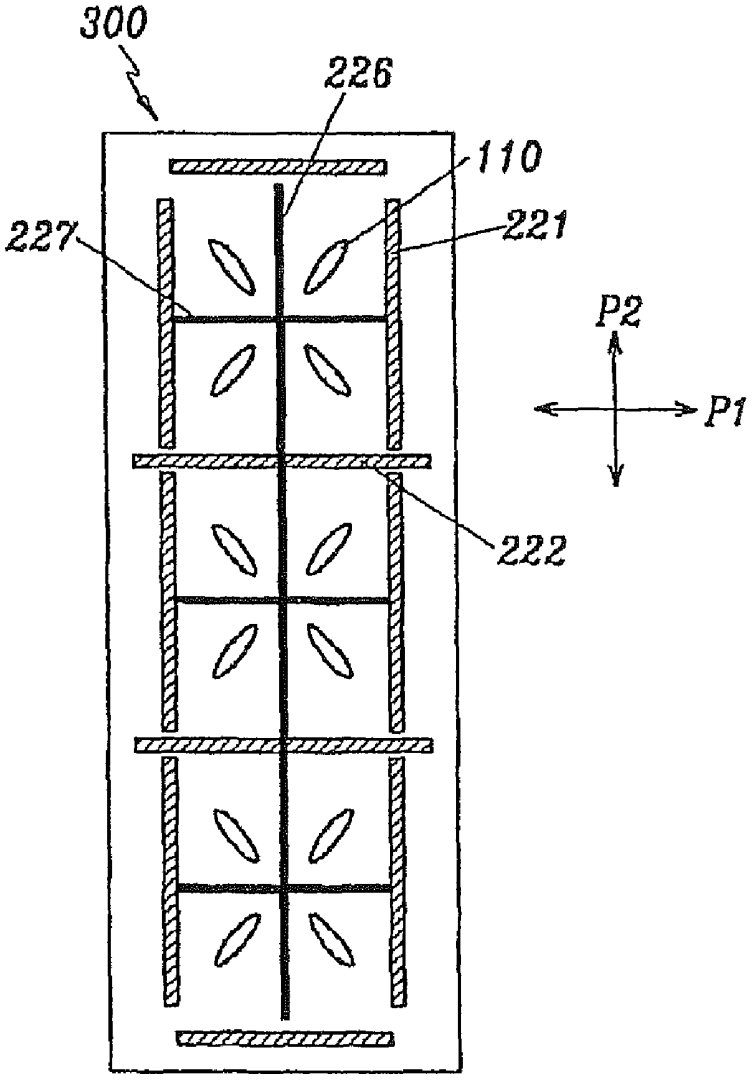


FIG. 6

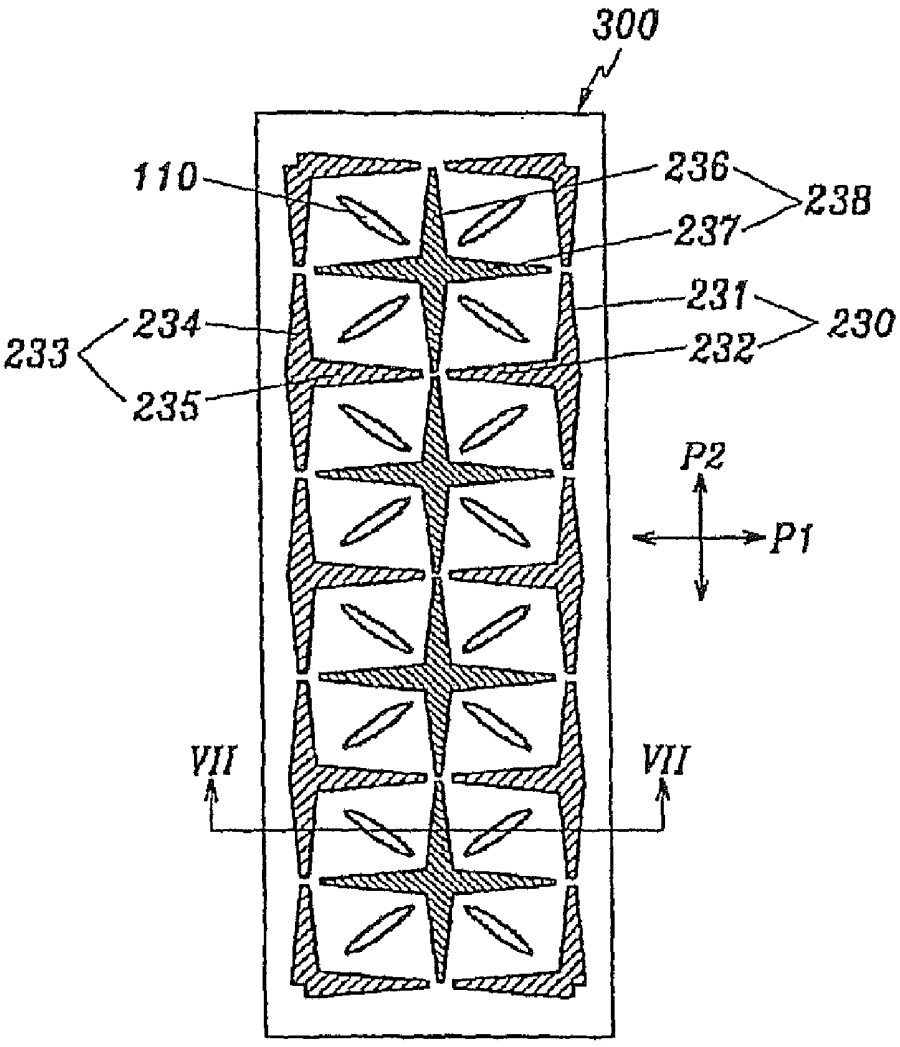


FIG. 7

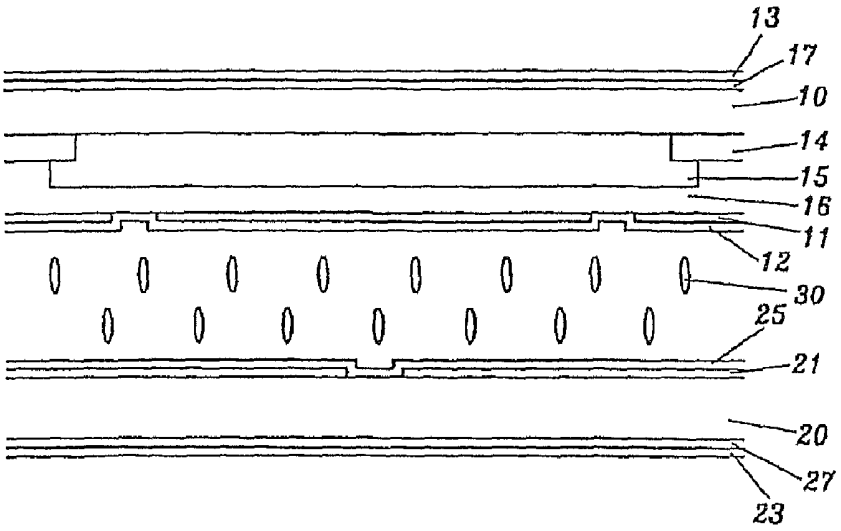


FIG. 8

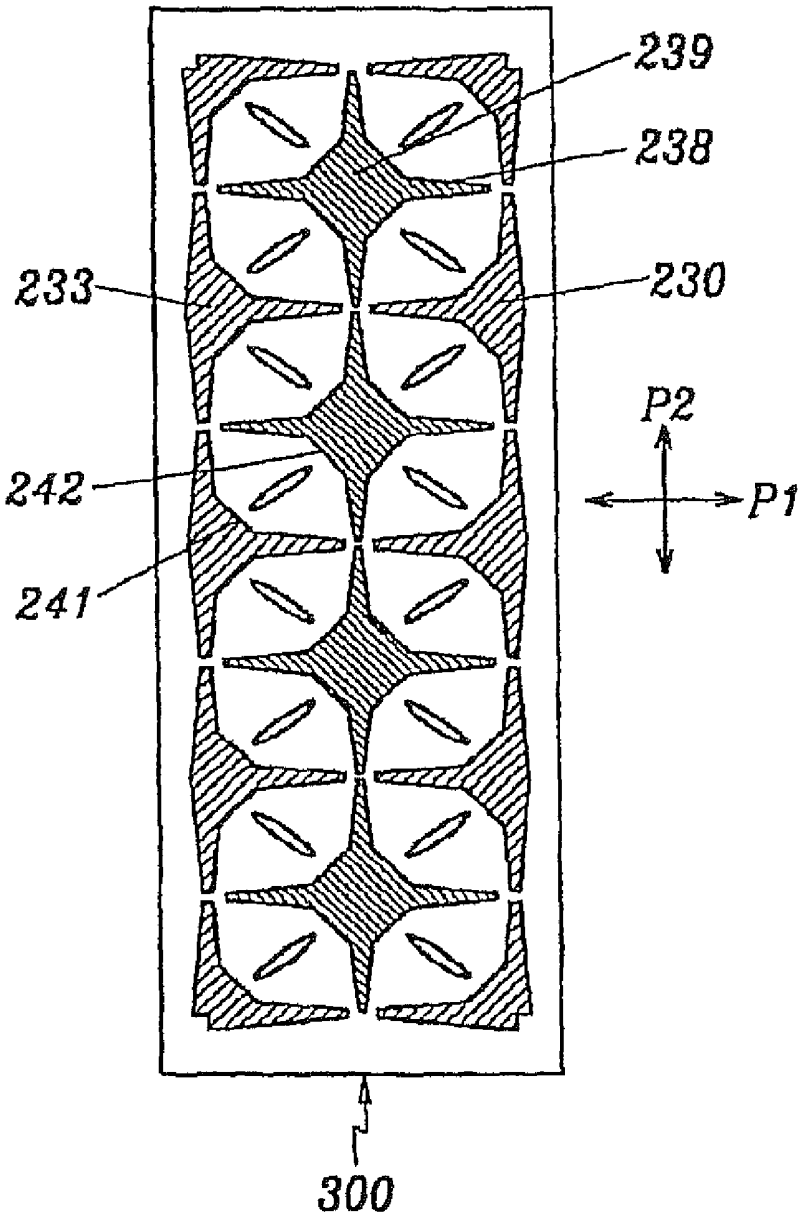


FIG. 9

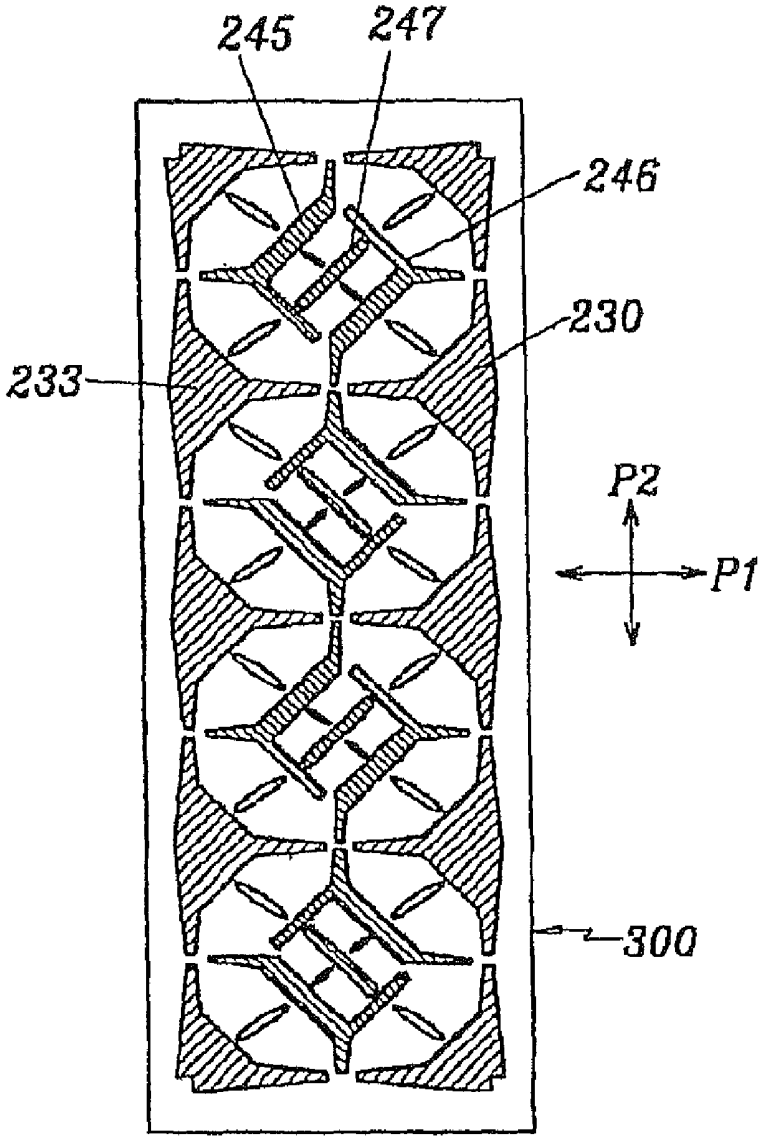


FIG. 10

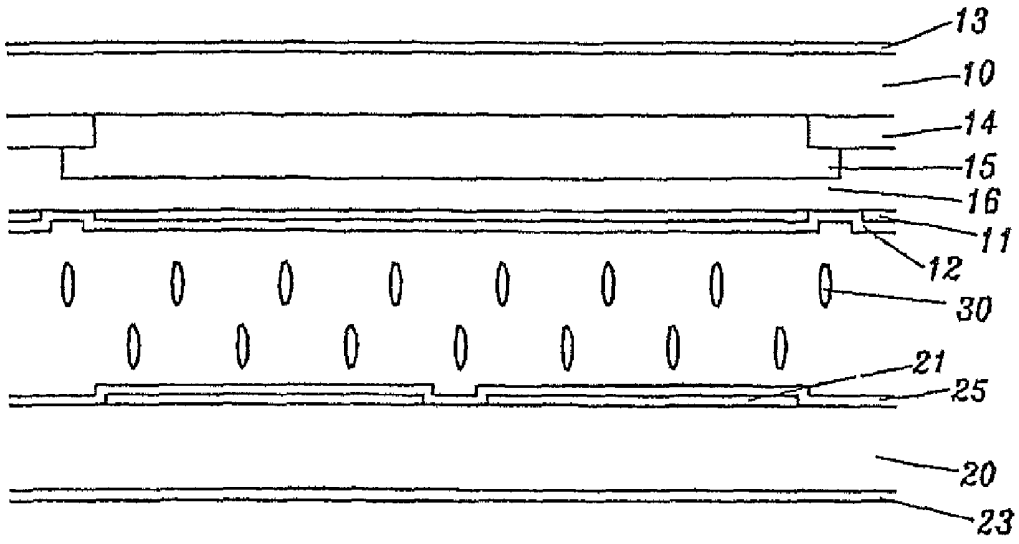
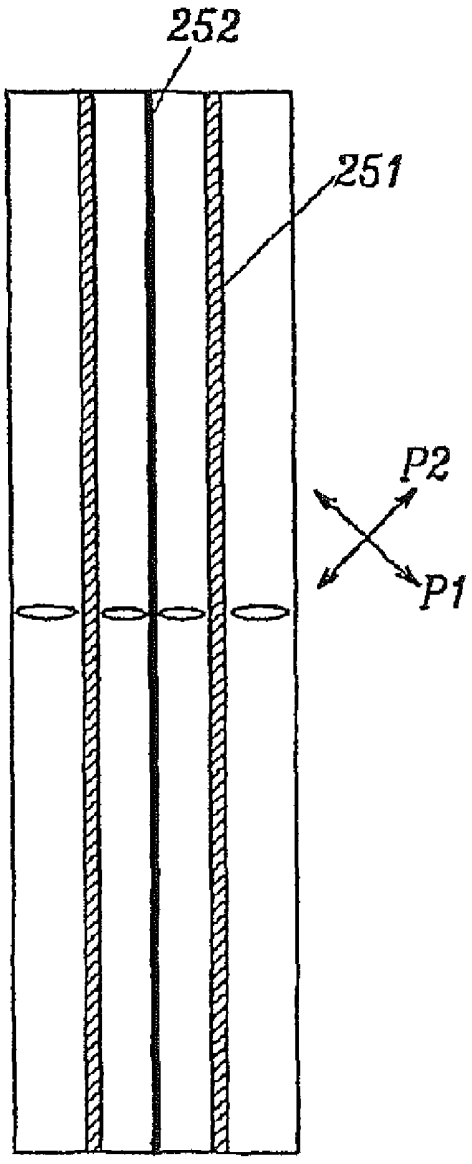


FIG. 11



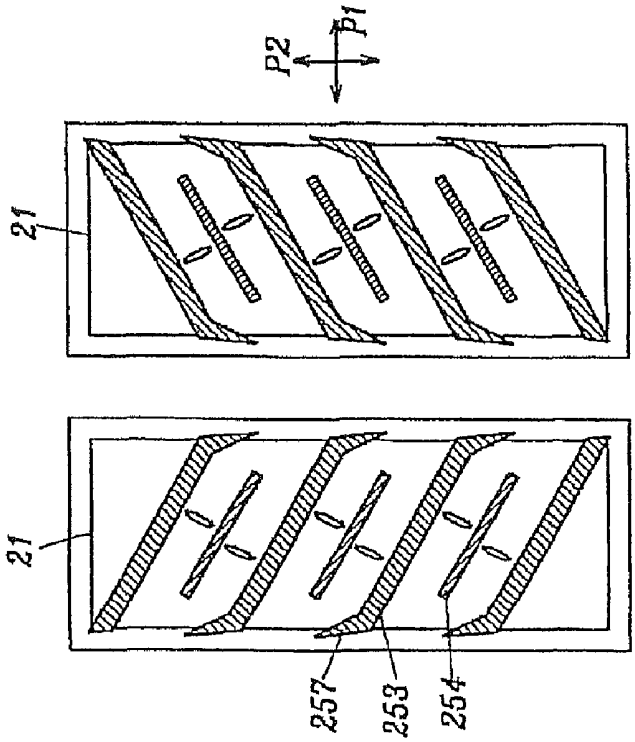


FIG. 13

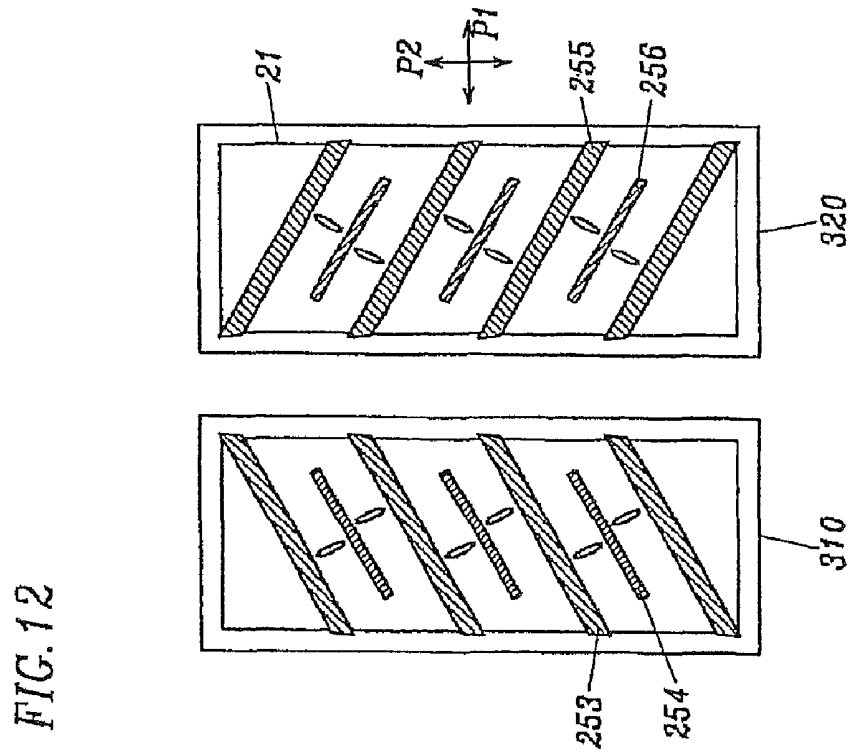


FIG. 12

FIG. 14

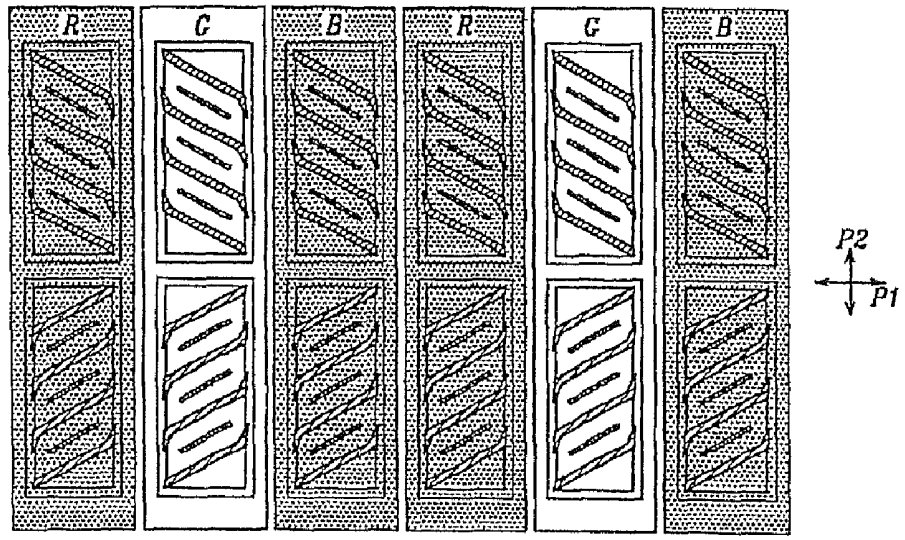
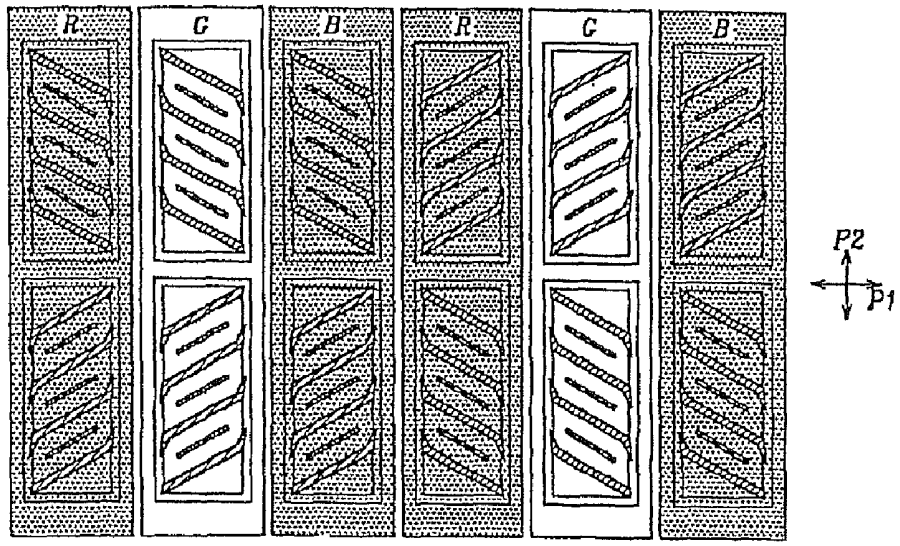


FIG. 15



LIQUID CRYSTAL DISPLAY HAVING WIDE VIEWING ANGLE

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation application of U.S. application Ser. No. 12/147,697 filed Jun. 27, 2008 and issued as U.S. Pat. No. 7,787,087, which is a divisional application of U.S. application Ser. No. 11/398,839 filed Apr. 6, 2006 and issued as U.S. Pat. No. 7,787,086, which is a continuation application of U.S. application Ser. No. 11/183,744 filed Jul. 19, 2005 and issued as U.S. Pat. No. 7,050,134, which is a continuation of U.S. application Ser. No. 10/861,397 filed Jun. 7, 2004 and issued as U.S. Pat. No. 6,937,311, which is a continuation application of U.S. application Ser. No. 10/269,861 filed Oct. 15, 2002 and issued as U.S. Pat. No. 6,778,244, which is a continuation application of U.S. application Ser. No. 10/020,303 filed Dec. 18, 2001 and issued as U.S. Pat. No. 6,512,568, which is a continuation application of U.S. application Ser. No. 09/314,293 filed May 19, 1999 and issued as U.S. Pat. No. 6,342,938, which claims priority to and the benefit of Korean Patent Application No. 1998-18037 filed on May 19, 1998, all of which are incorporated by reference herein in their entirety.

BACKGROUND OF THE INVENTION

(a) Field of the Invention

The present invention relates to a liquid crystal display having wide viewing angle.

(b) Description of the Related Art

A liquid crystal display (LCD) includes two substrates and a liquid crystal layer interposed therebetween. The transmittance of the incident light is controlled by the strength of the electric field applied to the liquid crystal layer.

A vertically aligned twisted nematic (VATN) liquid crystal display has a couple of transparent substrates which have transparent electrodes on their inner surfaces and a couple of polarizers attached to their outer surfaces. The VATN LCD further includes a liquid crystal layer between the two substrates, and the liquid crystal layer has chirality and negative dielectric anisotropy.

In the off state of the LCD, i.e., in the state that no voltage is applied to the electrodes, the long axes of the liquid crystal molecules are aligned perpendicular to the substrates.

When the sufficient voltage difference is applied to the electrodes, an electric field perpendicular to the substrates and the liquid crystal molecules are rearranged. That is, the long axes of the liquid crystal molecules tilt in a direction perpendicular to the field direction or parallel to the substrates due to the dielectric anisotropy, and twist spirally with a pitch due to the chirality.

As described above, since the long axes of the liquid crystal molecules in the off state is perpendicular to the substrates, the VATN LCD having crossed polarizers may have sufficiently dark state. Therefore, the contrast ratio of the VATN LCD is relatively high compared with the conventional TN LCD. However, the viewing angle of the VATN LCD may not be so wide due to the difference in retardation values among viewing directions.

To overcome the above-described problem, multi-domain structures formed by varying rubbing directions in the alignment layers or by forming apertures in the transparent electrodes are proposed. Clere disclosed a structure having linear apertures in a transparent electrode in U.S. Pat. No. 5,136,407, and Hirose et al. disclosed an LCD using fringe fields to make the long axes of the liquid crystal molecules to be aligned in a direction between polarizing directions in U.S. Pat. No. 5,229,873. On the other hand, Lien proposed a structure having X-shaped apertures in a transparent electrode in U.S. Pat. No. 5,309,264, and Histake et al. disclosed a structure having apertures in both of the electrodes in U.S. Pat. No. 5,434,690.

However, the proposed structures may not have a sufficiently wide viewing angle and the luminance in their on states is not so high.

SUMMARY OF THE INVENTION

It is therefore an object of the present invention to widen the viewing angle of an LCD.

It is another object of the present invention to reduce the disclination of an LCD.

These and other objects, features and advantages are provided, according to the present invention, by forming apertures in field generating electrodes.

In detail, a liquid crystal display according to the present invention includes a first and a second substrate facing each other and a first and a second electrodes on inner surfaces of the first and the second substrates respectively. The first and the second electrodes face each other, and have a plurality of first apertures and a plurality of second apertures, respectively.

According to an aspect of the present invention, the first and the second apertures form a substantially closed area.

According to another aspect of the present invention, the boundaries of the first and the second apertures are linear, curved or bent with an obtuse angle.

According to another aspect of the present invention, the width of the first and the second apertures becomes larger as goes from the ends to the center.

According to another aspect of the present invention, the width of the first and the second apertures are 3-20 μm.

According to another aspect of the present invention, the distance between the first and the second apertures are 5-20 μm.

The liquid crystal display according to the present invention may include a liquid crystal layer between the first and the second substrates, a first and a second alignment layers on the first and the second electrodes, respectively, and a first and a second polarizers attached on the outer surfaces of the first and the second substrates, respectively. The liquid crystal layer has negative dielectric anisotropy, and the first and the second alignment layer force the long axes of the liquid crystal molecules to align perpendicular to the first and the second substrates. The polarizing directions of the first and the second polarizers are preferably perpendicular to each other. It is preferable that the number of the average directions of the long axes of the liquid crystal molecules in the domains defined by the first and the second apertures are four. Preferably, the average directions makes 45°±10° with the polarizing directions of the first and the second polarizers, and the average directions of the adjacent domains are substantially perpendicular to each other.

The shape of the first and the second electrodes according to the present invention makes the liquid crystal layer therebetween to be divided into four regions having different average directions of the long axes, thereby causing wide viewing angle. In addition, disclination due to the disorder of the liquid crystal molecules is reduced by adjusting the widths and shapes of the apertures.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. **1**A and **1**B are schematic diagrams of a VATN LCD according to an embodiment of the present invention, respectively in black state and white state.

FIG. **2** is a schematic sectional view of a VATN LCD according an embodiment of the present invention

FIG. **3** is a layout view of apertures in electrodes of a VATN LCD according to the first embodiment of the present invention.

FIG. **4** is a sectional view of a liquid crystal display taken along the line IV-IV in FIG. **3**.

FIG. **5** is a layout view of apertures in electrodes of a VATN LCD according to the second embodiment of the present invention.

FIG. **6** is a layout view of apertures in electrodes of a VATN LCD according to the third embodiment of the present invention.

FIG. **7** is a sectional view of a liquid crystal display taken along the line IV-IV in FIG. **6**.

FIGS. **8** and **9** are layout views of apertures in electrodes of VATN LCDs according to the fourth and fifth embodiments of the present invention.

FIG. **10** is a sectional view of a liquid crystal display according to an embodiment of the present invention.

FIGS. **11** to **15** are layout views of apertures in electrodes of VATN LCDs according to the sixth to tenth embodiments of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention will now be described more fully hereinafter with reference to the accompanying drawings, in which preferred embodiments of the present invention are shown. This invention may, however, be embodied in different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. In the drawings, the thickness of layers and regions are exaggerated for clarity.

FIGS. **1**A and **1**B are schematic diagrams of a VAIN LCD according to an embodiment of the present invention, respectively in black state and white state.

As shown in FIGS. **1**A and **1**B, two glass or quartz insulating substrates **10** and **20** faces each other with being spaced apart from each other. Field generating electrodes **11** and **21** made of a transparent conductive material such as ITO (indium tin oxide) or the like are formed on the inner surfaces of the substrates **10** and **20**, respectively, and homeotropic alignment layers **12** and **22** are formed thereon, respectively. A liquid crystal layer **100** including a nematic liquid crystal having negative dielectric anisotropy is interposed between the substrates **10** and **20**. The liquid crystal layer **100** may have chirality or the alignment layers **12** and **22** may be rubbed in some directions so that the director of the liquid crystal layer **100** twists from the one alignment layer to the other. Polarizers **13** and **23** are attached on the outer surfaces of the substrates **10** and **20**, respectively, and polarize the rays out of the liquid crystal layer **100** and the rays incident on the liquid crystal layer **100**, respectively. The polarizing directions of the polarizers **13** and **23** are perpendicular to each other. The alignment layers **12** and **22** may be rubbed or not.

FIG. **1**A shows the off state that there is no potential difference between the electrodes **11** and **21**. In this case, long axes or molecular axes of the liquid crystal molecules **110** in the liquid crystal layer **100** are aligned perpendicular to the surfaces of the substrates **10** and **20** due to the aligning force of the alignment layers **12** and **22**.

In this state, the incident light linearly polarized by the polarizer **23** attached to the lower substrate **20** passes through the liquid crystal layer **100** without changing its polarization. Then, the light is blocked by the analyzer **13** attached to the upper substrate **10** to make the LCD in a black state.

When the potential difference is applied between the two electrodes **11** and **21**, an electric field perpendicular to the substrates **10** and **20** are generated, and thus the liquid crystal molecules are rearranged.

FIG. **1**B shows the on state that the sufficient electric field due to the high potential difference between the electrodes **11** and **21** is applied to the liquid crystal layer **100**. The molecular axes of the liquid crystal molecules in the liquid crystal layer **100** becomes perpendicular to the field direction or parallel to the substrates **11** and **21** due to the dielectric anisotropy. However, the molecules **110** near the surface of the alignment layers **12** and **22** remains in its initial state since the aligning force by the alignment layers **12** and **22** is much larger than the force due to the dielectric anisotropy. Furthermore, the liquid crystal director twists spirally due to the chirality or rubbing. By adjusting the chirality of the liquid crystal layer **100**, the twist angle of the liquid crystal director from the lower substrate **10** to the upper substrate **20** may made to be 90°.

The incident light linearly polarized by the polarizer **23** passes through the liquid crystal layer **100** and its polarization rotates by 90° according to the twist of the liquid crystal director. Therefore, the light passes through the analyzer **13** to make the LCD in a white state.

FIG. **2** shows the schematic structure of a VATN LCD having apertures in electrodes according to an embodiment of the present invention. For convenience, only substrates and electrodes are depicted and the other elements such as alignment layers are abbreviated.

As shown in FIG. **2**, field-generating electrodes **11** and **21** are formed on the upper and the lower substrates **10** and **20**, respectively, and the electrode **21** formed on the lower substrate **20** has an aperture **200**.

In absence of electric field, the long axes of the liquid crystal molecules **110** are aligned perpendicular to the substrates **10** and **20**, as shown in FIG. **1**A.

If the electrodes **11** and **21** have potential difference, an electric field is generated. Although the field direction in most regions is perpendicular to the substrates **10** and **20**, the field direction near the aperture **200** is not completely perpendicular to the substrates **10** and **20**, and the electric field is symmetrical with respect to the aperture **100**. The electric field near the aperture **200** is called the fringe field. The long axes of the liquid crystal molecules are not perpendicular to the substrates **10** and **20** and make some angle. The arrangement of the liquid crystal molecules are almost symmetrical with respect to the aperture **200** and the liquid crystal molecules in opposite regions with respect to the aperture **200** are arranged in opposite manner, thereby causing wide viewing angle.

The strength of the fringe field is large near the aperture and becomes smaller as goes far from the aperture. Accordingly, if the distance between the apertures is properly adjusted, the liquid crystal molecules located between the apertures are sufficiently affected by the fringe field. The liquid crystal layer is divided into several regions or domains defined by the apertures, and the average axial direction, which means the average direction of the long axes of the liquid crystal molecules, in each domain is varied according to the shapes and arrangement of the apertures.

Since the aperture **200** is formed when a conductive layer is patterned to form the electrode **21** by using photolithography, no separate step for forming the aperture **20** is required, and thus it is very easy to obtain a multi-domain LCD compared with other methods using such as rubbing. In addition, the locations and the shapes of the domains can be finely adjustable because of the use of the photolithgraphy. In the meantime, a plurality of wires (not shown) for supplying signals to the electrode **21** may be provided on the lower substrate **20**. In this case, portions of the electrode **11** on the upper substrate **10** located at the position corresponding to wires on the lower substrate **20** may be removed in order to reduce the parasitic capacitance between the electrode **11** and the wires.

As described above, the apertures **200** may have various shapes and arrangements, and the apertures may be formed in both electrodes or either of the electrodes. Since the shapes and arrangements of the apertures affects on the average axial directions of the domains and characteristics such as luminance, response time and afterimages, etc., of the LCD panels, they should be properly designed.

The aperture pattern for a multi-domain LCD according to the present invention satisfies the following conditions:

First, it is preferable that the number of the domains which have different average axial directions, especially in a pixel, is at least two, and more preferably the number is four. The average axial direction of each domain, when viewed from the top, preferably makes 45°±10°, more preferably 45° with the polarizing directions of the polarizers especially when using crossed polarizers. In addition, it is preferable that the average axial directions of the adjacent domains are perpendicular to each other.

Second, it is preferable that the apertures on the upper and the lower substrates form substantially closed areas and thus substantially closed domains, when viewed from the top. It is because that the texture where the arrangement of the liquid crystal molecules is disordered is generated near the ends of the apertures, and thus the ends of the apertures are preferably closely located. Furthermore, the boundaries of the apertures are preferably linear, slowly curved or bent with an obtuse angle in order to make the arrangement of the liquid crystal molecules to be uniform, thereby reducing the response time. In particular, when the apertures on the lower and upper substrates face each other and form a substantially closed area, it is preferable that the boundaries of the facing portions of the apertures are preferably linear, slowly curved or bent with an obtuse angle. It is preferable that the width of the aperture becomes larger as goes from the ends to the center. The aperture patterns may be rectangular.

Finally, the width of the aperture and the distance between the apertures are preferably 3-20 μm and 5-20 μm. If the width of the aperture is larger than the former value or the distance between the apertures is less than the latter value, the aperture ratio is reduced, thereby reducing luminance and transmittance. On the contrary, if the width of the aperture is less than the former value or the distance between the apertures is larger than the latter value, the strength of the fringe field becomes week, thereby increasing response time and generating disordered textures.

Now, considering these conditions, the first embodiment of the present invention will be described with reference to FIGS. **3** and **4**. Although an LCD has a plurality of pixels, FIGS. **3** and **4** show a single pixel region **300**. In addition, only aperture patterns are illustrated in FIGS. **3** and **4**, and other elements such as TFTs, wires, etc., are not illustrated.

As shown in FIGS. **3** and **4**, a plurality of linear apertures **211**, **212**, **216** and **217** are formed in a rectangular pixel region **300**. A plurality of first and second apertures **211** and **212** extending in transverse and longitudinal directions respectively are formed in an electrode **11** on an upper substrate **10**, and a cross-shaped aperture **216** and **217** including first and second portions **216** and **217** extending in the transverse and longitudinal directions respectively are formed in an electrode **21** on a lower substrate **20**.

The first and the second apertures **211** and **212** are separated from each other, arranged in the longitudinal direction, and form four large squares which is substantially closed.

The first portion **216** of the lower aperture passes through the center of the pixel **300** in the longitudinal direction, and thus through the center of the large squares formed by the first and the second apertures **211** and **212**, and both ends of the first portion **216** approaches the second apertures **212**. The plurality of second portions **217** passes through the center of the large squares in the transverse direction, and both ends of the second portion **216** approaches the first apertures **211**.

As a result, the apertures **211**, **212**, **216** and **217** form small squares which define domains, and two edges of the small square is two apertures **211** and **212** on the upper substrate **10**, while the other two edges of the small square is two apertures **216** and **217** on the lower substrate **20**.

The arrangement of the liquid crystal molecules is described with reference to FIG. **4**.

As shown in FIG. **4**, the liquid crystal molecules incline due to the fringe field near the apertures. The adjacent apertures **211** and **216** on the different substrates **10** and **20** result in a fringe field which forces the liquid crystal molecules between the apertures **211** and **216** to align in the same direction, i.e., the direction from the aperture **216** to the aperture **211**. Accordingly, the tilt directions of the liquid crystal molecules in the opposing regions with respect to the apertures are different.

In the meantime, since the adjacent apertures defining a domain are perpendicular to each other, the director of the liquid crystal layer varies in accordance with position. However, the average axial direction in a square domain becomes the direction from the intersection of the first and the second portions **216** and **217** to the intersection of the extensions of the first and the second apertures. That is, the average axial direction in a square domain is the direction from the center to the corner of the large square formed by the first and the second apertures **211** and **212**. This arrangement of the aperture makes sixteen square domains in a pixel, and the average axial direction of each domain is one of four directions. The average axial directions of the adjacent domains are perpendicular to each other when viewed from the top.

When the polarizing directions P**1** and P**2** of the polarizers are aligned in the transverse and the longitudinal directions respectively, the polarizing directions P**1** and P**2** have an angle of 45° relative to the average axial direction of each domain when a sufficient voltage is applied.

In the LCDs having the aperture pattern shown in FIG. **3**, the liquid crystal molecules are rearranged by the force due to the electric field immediately after the voltage is applied. However, the arrangement of the liquid crystal molecules is slowly changed by the tendency to be parallel to each other, which the molecules of the nematic liquid crystal have. Accordingly, it takes some time to reach a stable state that the movement of the liquid crystal molecules disappears, thereby causing large response time.

An aperture pattern according to the second embodiment of the present invention shown in FIG. **5** is similar to the aperture pattern shown in FIG. **3** except for rectangular shape of the domains instead of square shape. That is, longitudinal apertures **221** and **226** are longer than transverse apertures **222** and **227**. Accordingly, when viewed from the top, an

angle made by the average axial directions in the adjacent domains is not exactly 90°, and an angle between the polarizing directions and the average axial directions is not exactly 45°. However, in this case, one of the transverse or longitudinal directions is preferred by the liquid crystal molecules because the long axes of the liquid crystal molecules makes a less angle with one of the two directions than with the other. Since the rearrangement of the liquid crystal molecules quickly occurred and becomes stable, the response time is relatively short than the LCD shown in FIG. **3**.

A liquid crystal display exhibiting less response time is now described.

FIG. **6** is a layout view of an aperture pattern of an LCD according to a third embodiment of the present invention, and FIG. **5** is a sectional view of the LCD shown in FIG. **6** taken along the line VII-VII'.

As shown in FIGS. **6** and **7**, an LCD according to the third embodiment of the present invention includes a lower TFT (thin film transistor) panel **20** and an upper color filter panel **10**. Though it is not shown in the figures, a plurality of gate lines and data lines are formed on the inner surface of the TFT panel **20**, and a pixel electrode **20** and a TFT (now shown) as a switching element are formed in a lower pixel region surrounded by the gate lines and data lines. On the inner surface of the color filter panel **10** opposite to the TFT panel **20**, a black matrix pattern **14** which defines an upper pixel region corresponding to the lower pixel region in the TFT panel is formed, and a color filter **15** is formed therebetween. A passivation layer **16** covers the black matrix **14** and the color filter **15**, and a common electrode **11** is formed thereon. A plurality of apertures **230**, **233** and **238** are formed in the common electrode **11** and the pixel electrode **21**, and homeotropic alignment layers **25** and **15** are formed on the pixel electrode **21** and the common electrode **11**, respectively.

Polarizers **13** and **23** are attached to the outer surfaces of the substrates **10** and **20**, respectively, and retardation films **17** and **27** are interposed between the polarizers **13** and **23** and the substrates **10** and **20**, respectively. An a-plate compensation film and a c-plate compensation film may be attached to respective substrates, or two c-plate compensation films may be attached the both substrates **10** and **20**. A biaxial compensation film may be used instead of the uniaxial compensation film, and, in this case, the biaxial compensation film may be attached to only one substrate. The slow axis, which is the direction having a largest refractive index, of the a-plate or biaxial compensation film may be parallel or perpendicular to the polarizing directions. It is preferable that the second slow axis of the biaxial compensation film coincides the transmission or absorption axes of the polarizers.

The shapes of the apertures **230**, **233** and **238** are basically similar to those of the LCD shown in FIG. **3** according to the first embodiment. In detail, the apertures **230** and **233** on the color filter panel **10** includes longitudinal parts **231** and **234** and transverse parts **232** and **235** extending from the center of the longitudinal parts **231** and **233** in the left or right direction. The apertures **233** and **230** located near the left and right edges of the pixel is symmetrically arranged with respect to the longitudinal central line of the pixel, and form four large rectangles (almost squares) arranged in the longitudinal direction. The plurality of the apertures **238** on the TFT panel **20** have cross shapes including transverse parts **237** and longitudinal parts **236** crossing each other, and the centers of the apertures **238** are located at the center of the large rectangles.

It is preferable that the ends of the apertures **230**, **233** and **238** on the substrates **10** and **20** are as close as possible such that the domain defined by the apertures **230**, **233** and **238** form a substantially closed area when viewed from the top.

The width of the apertures **230**, **233** and **238** is largest at the center, and decreases as goes to the ends. Therefore, the boundaries of the apertures **230**, **233** and **238** are bent with obtuse angle, and the angle made by two apertures on the different substrates are acute angle when viewed from the top. As a result, the domain defined by the apertures **13** and **23** has the diagonal substantially perpendicular to the average axial direction which is longer than the diagonal substantially parallel to the average axial direction. The ratio of the diagonal perpendicular to the average axial direction with respect to the diagonal parallel to the average axial direction becomes larger if the width difference between the central portion and the end portion of the apertures **230**, **233** and **238** is more enlarged at the bent point. Since the liquid crystal molecules become more uniformly aligned as the apertures **13** and **23** are parallel to each other, the response time becomes reduced as the ratio becomes large.

In this embodiment, the average axial directions of the adjacent domains makes 90 degrees, and the polarizing directions P**1** and P**2** of the polarizers **13** and **23** are perpendicular to each other and makes 45 degrees with the average axial direction of each domain.

According to the third embodiment, four tetragonal rings formed of the apertures exist in a unit pixel. However, the number of the rings may vary according to the conditions such as the size of the pixel. Still, to obtain the optimum luminance, the apertures preferably form regular tetragonal rings.

The width of the apertures **230**, **233** and **238** is preferably in the range of 3-20 μm as described above.

The distance between the central points of the apertures **230**, **233** and **238** on the different substrates **10** and **20**, which is largest distance between the apertures, is in the range of 10-50 μm and more preferably in the range of 23-30 μm. However, it depends on the size or the shape of the pixel.

Now, a fourth embodiment of the present invention is described with reference to FIG. **8**.

As shown in FIG. **6**, the shape of apertures is similar to that of the third embodiment. However, the boundaries of the apertures **230**, **233** and **238** are bent twice while those in the third embodiment once, when only a domain is considered. In addition, considering only a domain, the edges **241** and **242** generated by the twice bending of the boundaries of the apertures **230**, **233** and **238** on the different substrates **10** and **20** are parallel to each other. In other words, the central portions of the apertures **230**, **233** and **238** expand to the center of the domain, the central portions **239** of the apertures **238** becomes square. Accordingly, the distance between the apertures **230**, **233** and **238** becomes much smaller, and the boundaries of the apertures **230**, **233** and **238** approaches linear shape, thereby decreasing response time. However, since the area occupied by the apertures **233**, **233** and **238** becomes larger, the aperture ratio decreases.

To solve this problem, the central portion **239** of the aperture **238** on the lower substrate **20** in the fourth embodiment becomes square ring instead of square in the fifth embodiment. The cross shaped aperture **238** is divided two portions **245** and **246** in order to prevent the isolation of the portion of the electrode surrounded by the central portion of the aperture **238**. That is, two adjacent edges of the square ring is connected to each other, but disconnected to the remaining two edges. Furthermore, an aperture **247** parallel to the opposing edges of the square ring is added. As a result, two domains are added in the square ring, and the aperture ratio increases.

In the first to the fifth embodiments of the present invention, aperture ratio and luminance may be improved if edge

portions of the apertures **230** and **233** on the upper substrate **10** are placed outside the pixel electrode **21** as shown in FIG. **10**.

The shapes of the apertures on the two substrates may be exchanged.

In order to obtain less response time, it is preferable that the apertures on the different substrates are parallel to each other, which is the sixth embodiment shown in FIG. **11**.

A linear aperture **252** extending longitudinally is formed in the center of a pixel electrode on a TFT panel **20**, and two linear longitudinal apertures **251** on a color filter panel **10** are located left and right to the aperture **252**, and thus the apertures on the different substrates are arranged alternately. Polarizing directions P**1** and P**2** are perpendicular to each other and make an angle of 45° with respect to the extension of the apertures **251** and **252**.

In this case, since the liquid crystal molecules in a domain uniformly incline in the same direction, i.e., the direction perpendicular to the aperture, the response time is very fast as about 30 ms. However, in this case, only 2 average axial directions are generated, and the viewing angle is not good compared with the former embodiments.

Another aperture pattern for obtaining fast response time as well as four average axial directions is provided in the seventh embodiment of the present invention shown in FIG. **12**.

FIG. **12** shows two adjacent pixels **310** and **320** and an aperture pattern formed thereon. Apertures **253** and **255** on the upper substrate **10** and apertures **254** and **256** extend obliquely to make an angle with the transverse and the longitudinal directions. The apertures **253**, **254**, **255** and **256** in a pixel **310** and **320** are parallel to each other, and the extensions of the apertures in the adjacent pixels makes an angle such as 90 degrees. In this case, a pair of pixels yields 4 different average axial directions.

Polarizing directions P**1** and P**2** are aligned in the transverse and longitudinal directions.

The disclination that the liquid crystal molecules are disordered may be generated near the intersections of the pixel electrodes and the apertures **254** and **256** on the lower substrate **20**, more exactly, at the portion where the apertures makes an obtuse angle with the pixel electrode. The disclination reduces the luminance of the LCD, and afterimage may be generated since the position of the disclination region varies according to the applied voltage.

FIG. **13**, which illustrate the eighth embodiment of the present invention, shows a branch **257** of the aperture **253** on the color filter substrate, which extends to the point where the boundary of the pixel electrode **21** and the aperture **253** make an obtuse angle along the edges of the pixel electrode **21**. The width of the branch **257** may gradually decrease from the connection with the apertures **253** to the ends. This shape decreases the disclination and increases the luminance.

According to the seventh and the eighth embodiments, two average axial directions exist in a pixel, and four average axial directions in a pair of the pixel regions.

The various arrangement of pixels having different average axial directions are possible, and these embodiments are shown in FIGS. **14** and **15**.

According to the ninth embodiment shown in FIG. **14**, the pixels arranged in the row direction has the same average axial direction, while the adjacent pixels in a column have different average axial directions. In order to make different average axial directions, the oblique angles of apertures is differentiated.

On the contrary, according to the tenth embodiment shown in FIG. **15**, the oblique angles of the apertures of adjacent pixels in a column are different, while, in row direction, the pixels in a dot including red, green and blue pixels has the same average axial direction, and the average axial direction is altered by unit of dot.

According to the embodiments of the present invention, multi-domain LCDs are formed using various aperture pattern to control the arrangement of liquid crystal molecules, therefore wide viewing angle is obtained, disclination is removed and the luminance is increased.

In the drawings and specification, there have been disclosed typical preferred embodiments of the invention and, although specific terms are employed, they are used in a generic and descriptive sense only and not for purposes of limitation, the scope of the invention being set forth in the following claims.

What is claimed is:

1. A liquid crystal display comprising:

a first substrate having an inner surface and an outer surface;

a gate line extending in a transverse direction on the inner surface of said first substrate;

a data line extending longitudinal direction on the inner surface of said first substrate;

a first electrode disposed on the inner surface of said first substrate;

a second substrate facing the first substrate and having an inner surface and an outer surface;

a second electrode disposed facing the first electrode on the inner surface of the second substrate;

a pixel region including a first edge extending in a transverse direction and a second edge extending in a longitudinal direction;

wherein

a plurality of groups each having adjacent domains divided by tilt directions of liquid crystal molecules, wherein a number of axial directions of the liquid crystal molecules in one of the plurality of groups having adjacent domains is four, and wherein at least two groups of the plurality of groups having adjacent domains are disposed in the pixel region;

a liquid crystal layer between the first substrate and the second substrate;

a first polarizer attached on the outer surface of said first substrate; and

a second polarizer attached on the outer surface of said second substrate,

wherein the axial direction of the liquid crystal molecules in each domain is tilted at an angle of 45°±10° with respect to polarizing directions of the first polarizer and the second polarizer,

wherein the polarizing direction of the first polarizer is substantially parallel to the first edge of the pixel region, and the polarizing direction of the second polarizer is substantially parallel to the second edge of the pixel region, and

wherein long axes of liquid crystal molecules in the liquid crystal layer are aligned perpendicular to the substrates in a state that no voltage is applied to the electrodes.

2. The liquid crystal display of claim **1**, wherein one of the groups of adjacent domains has a first boundary extending in a transverse direction and a second boundary extending in a longitudinal direction formed therebetween.

3. The liquid crystal display of claim 2, wherein one of the groups of adjacent domains has a point at which the first boundary and the second boundary intersect.

4. The liquid crystal display of claim 3, wherein the liquid crystal molecules in one of the groups of adjacent domains are tilted toward the point.

5. The liquid crystal display of claim 1, wherein the axial direction of the liquid crystal molecules in one of two domains adjacent to each other according to a transverse direction or a longitudinal direction, is tilted at an angle of 90°±10° with respect to the axial direction of the liquid crystal molecules in the other of two domains adjacent to each other according to a transverse direction or a longitudinal direction.

6. The liquid crystal display of claim 1, wherein the tilted shape of the liquid crystal molecules in one of the groups of adjacent domains substantially forms a diamond shape when viewed on a plane.

7. The liquid crystal display of claim 1, wherein the first electrode comprises a plurality of domain forming members.

* * * * *

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公开(公告)号	US8054430	公开(公告)日	2011-11-08
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摘要(译)

在一个基板上的公共电极中形成四边形环形孔，并且在与另一个基板上的像素电极中的四边形环形孔的中心对应的位置处形成十字形孔。两个电极之间的液晶层被分成四个区域，其中当向电极施加电压时，液晶层的指向矢具有不同的角度。相邻领域的董事是直角的。四边形环形孔在四边形的每一侧的中点处断裂，并且孔的宽度随着从弯曲点到边缘的减小而减小。通过四个区域获得宽视角，其中液晶层的指向矢指示不同的方向，去除向错并且亮度增加。