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(19) **United States**(12) **Patent Application Publication**
KUBOKI et al.(10) **Pub. No.: US 2016/0139466 A1**(43) **Pub. Date: May 19, 2016**(54) **LIQUID CRYSTAL DISPLAY DEVICE AND
METHOD FOR MANUFACTURING SAME****G02F 1/1333** (2006.01)**G02F 1/1335** (2006.01)(71) Applicant: **SHARP KABUSHIKI KAISHA, Osaka**
(JP)(52) **U.S. Cl.**CPC **G02F 1/133753** (2013.01); **G02F 1/133788**
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G02F 2001/133761 (2013.01); **G02F**
2001/133531 (2013.01); **G02F 2001/133541**
(2013.01); **G02F 2001/13712** (2013.01); **G02F**
2001/133742 (2013.01)(72) Inventors: **Ken KUBOKI, Osaka-shi (JP); Yusuke**
NISHIHARA, Osaka-shi (JP)(21) Appl. No.: **14/899,841**(22) PCT Filed: **Feb. 27, 2014**(86) PCT No.: **PCT/JP2014/054961**

§ 371 (c)(1),

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Jun. 20, 2013 (JP) 2013-129989

Publication Classification(51) **Int. Cl.****G02F 1/1337** (2006.01)**G02F 1/137** (2006.01)(57) **ABSTRACT**

A liquid crystal display device (100) includes a liquid crystal layer (30) of a vertical alignment type, a first photo-alignment film (12), and a second photo-alignment film (22). The first photo-alignment film includes a first pre-tilt region (12a) and a second pre-tilt region (12b) defining pre-tilt directions (PD1, PD2) that are anti-parallel to each other. The second photo-alignment film includes a third pre-tilt region (22a) and a fourth pre-tilt region (22b) defining pre-tilt directions (PD3, PD4) that are anti-parallel to each other. The entire boundary (BD1) between the first pre-tilt region and the second pre-tilt region and the entire boundary (BD2) between the third pre-tilt region and the fourth pre-tilt region are aligned with each other, as seen from the display plane normal direction.

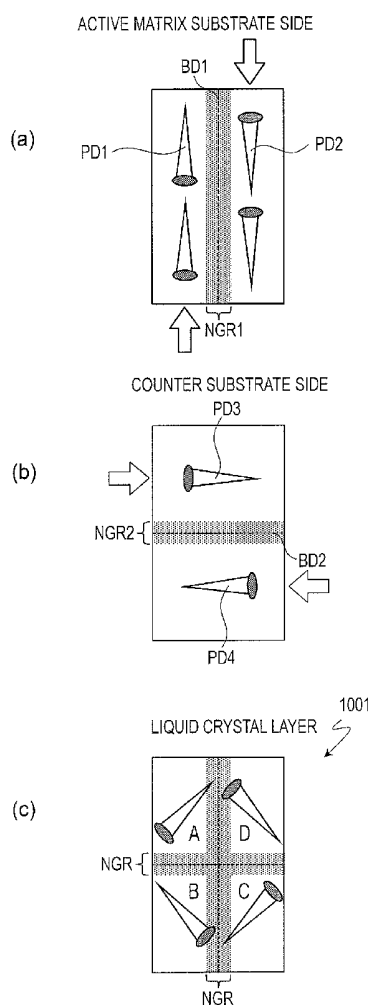


FIG. 1

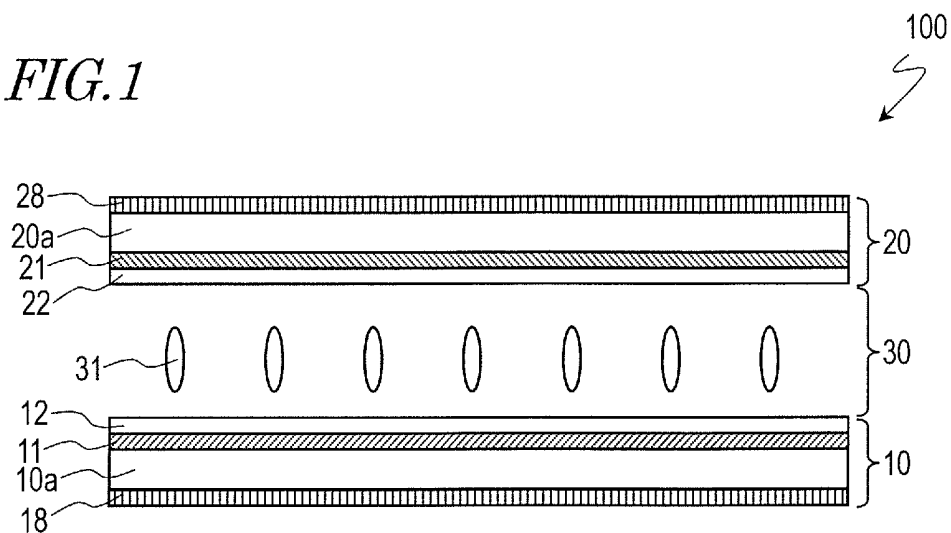


FIG. 2

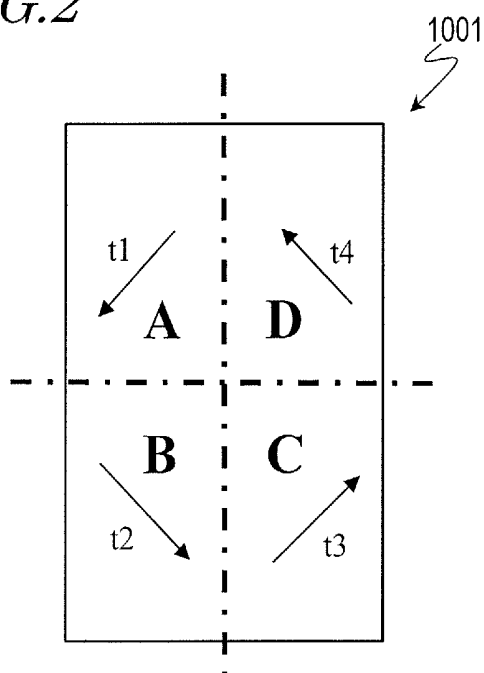
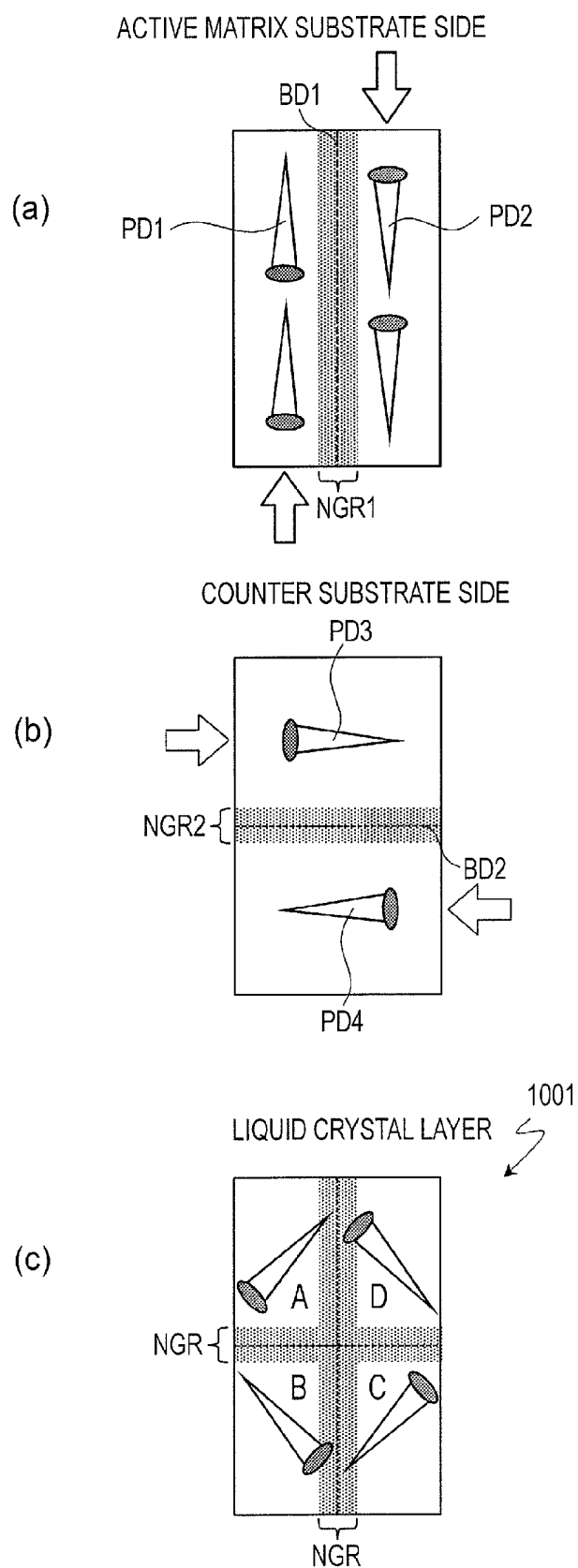


FIG. 3



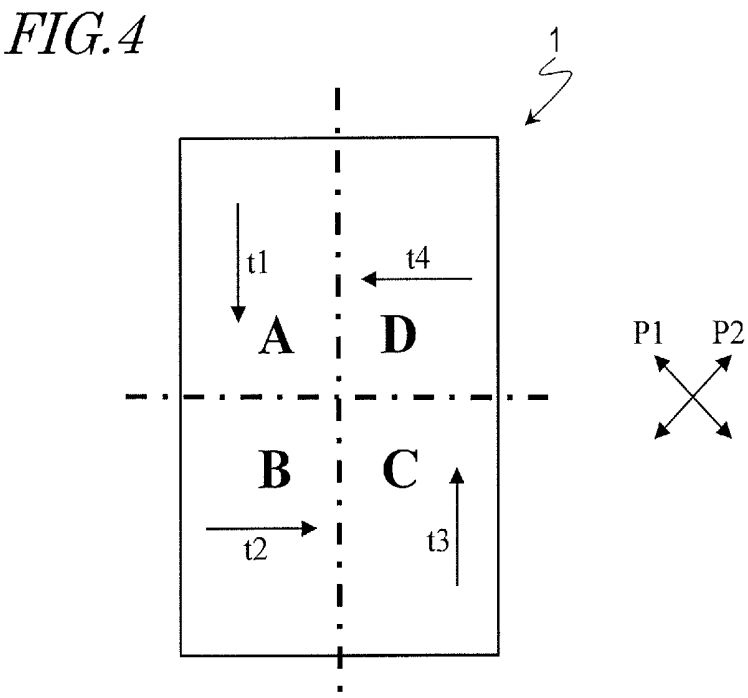


FIG. 5

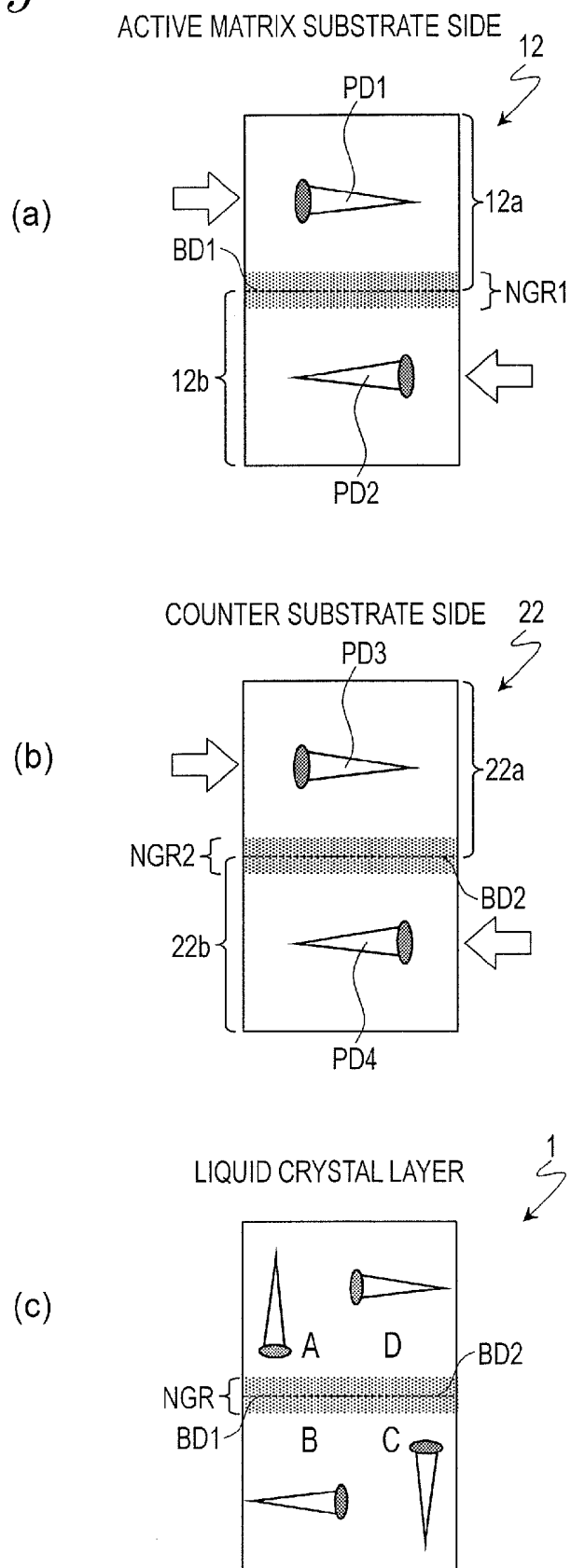


FIG. 6

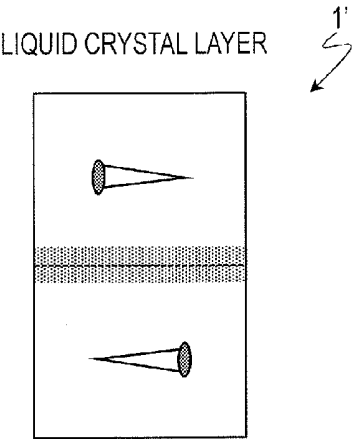


FIG. 7

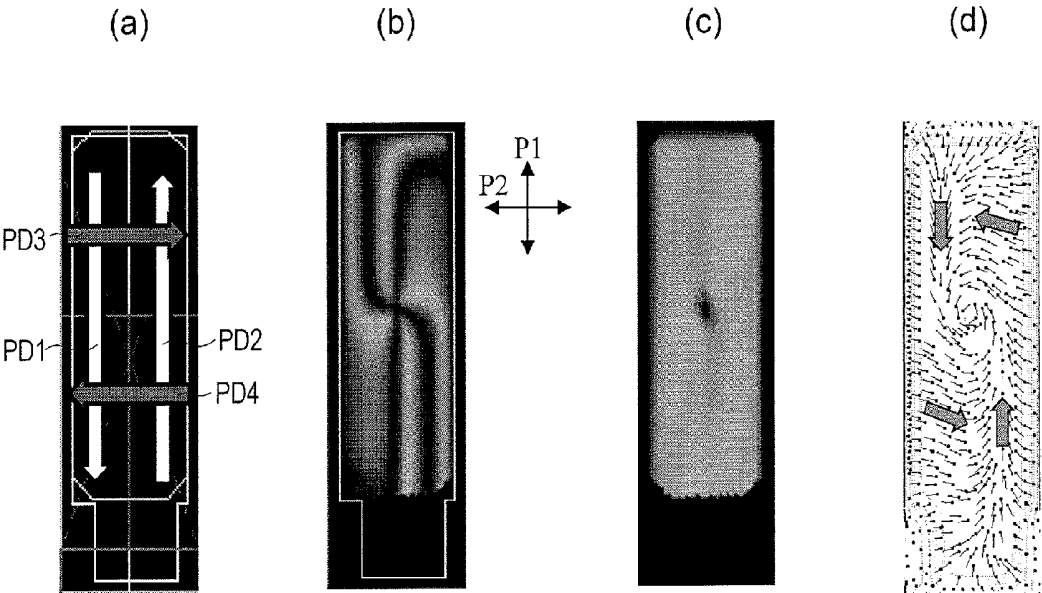


FIG. 8

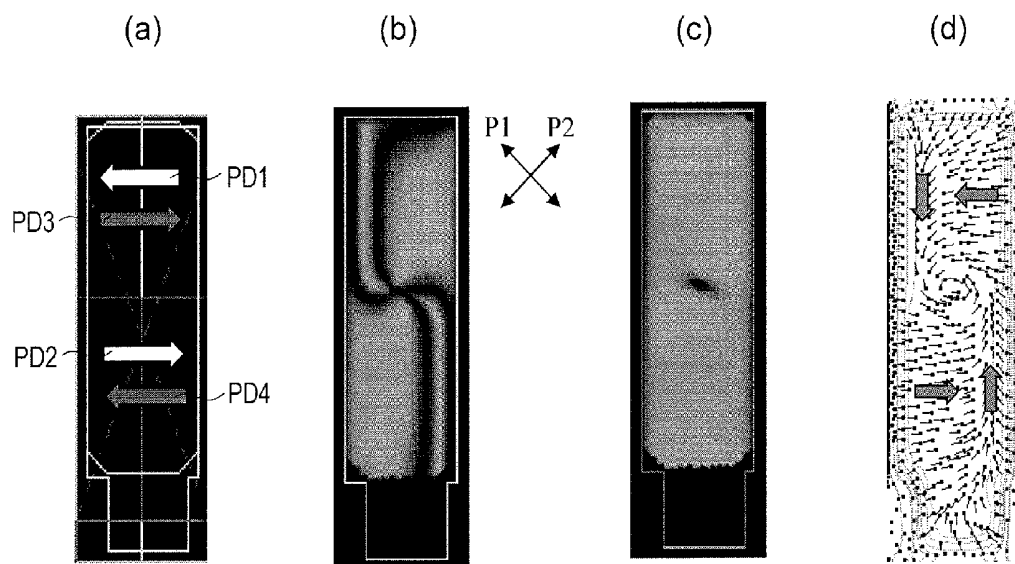


FIG. 9

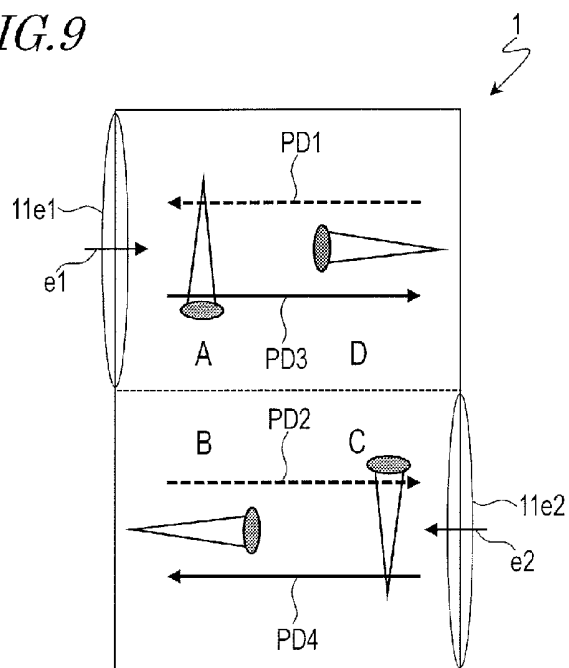


FIG. 10

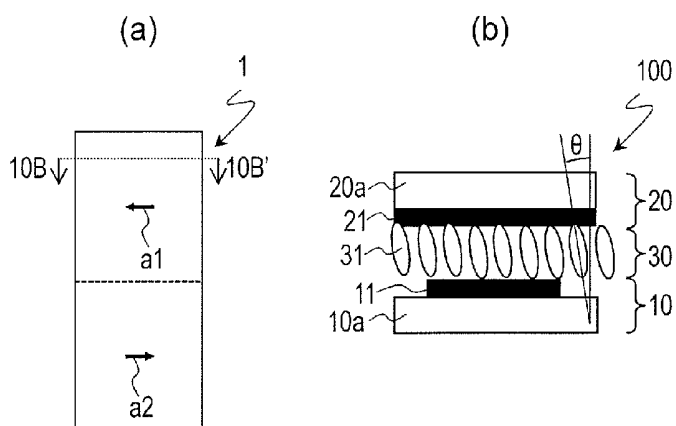


FIG. 11

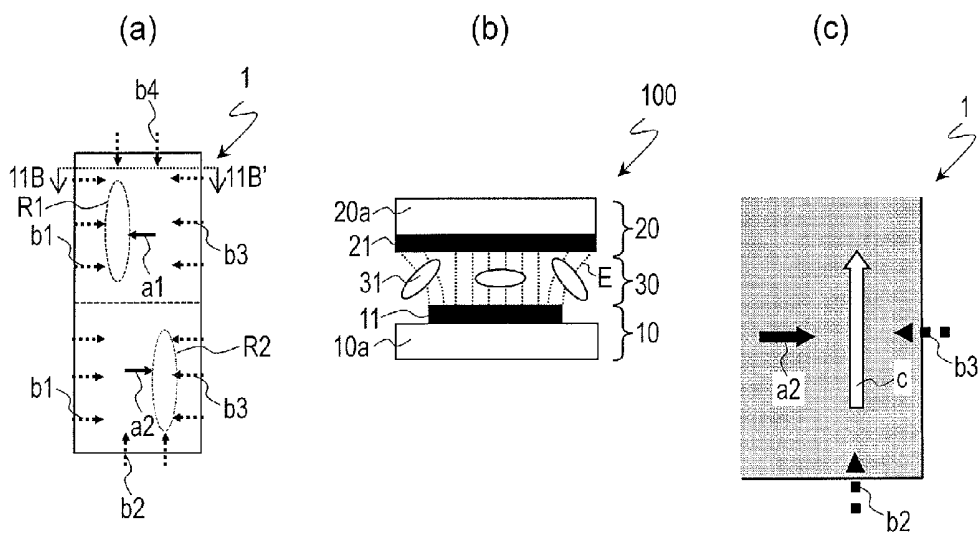


FIG. 12

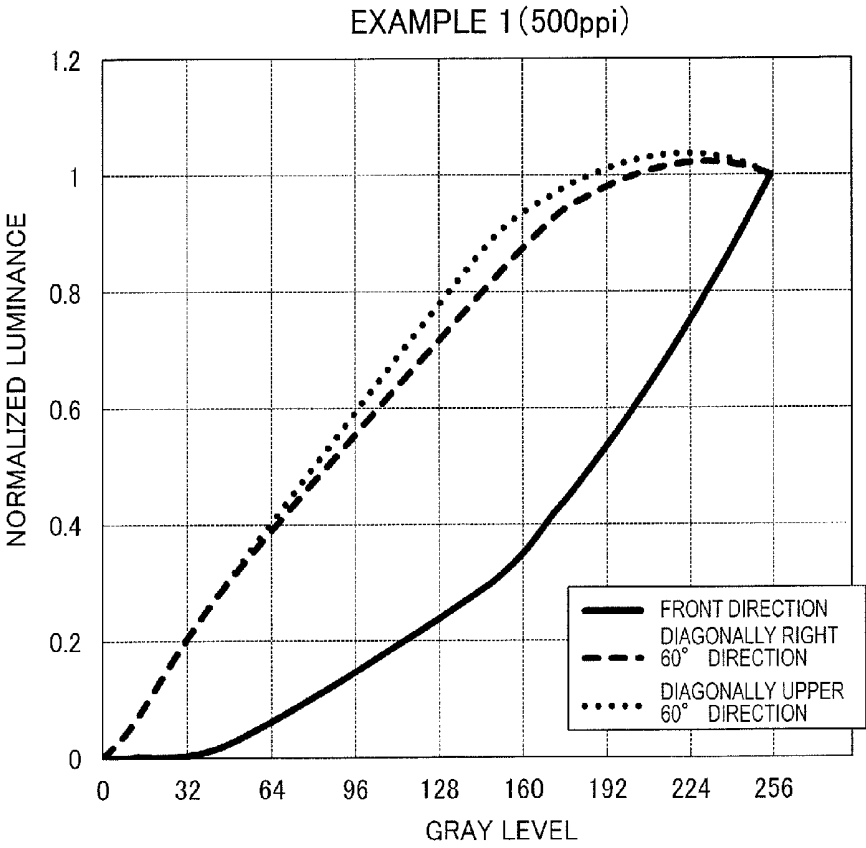
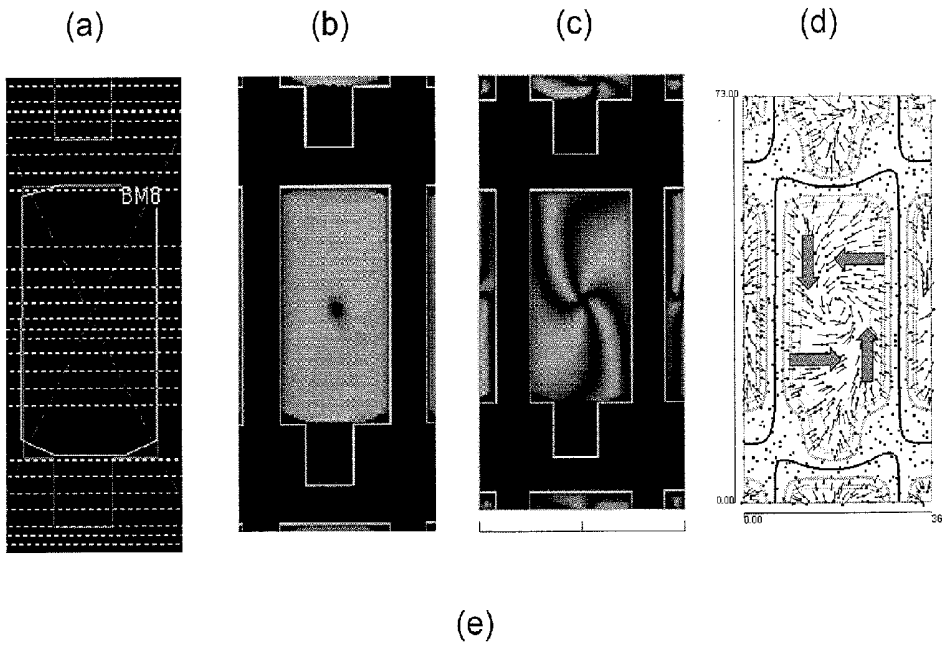
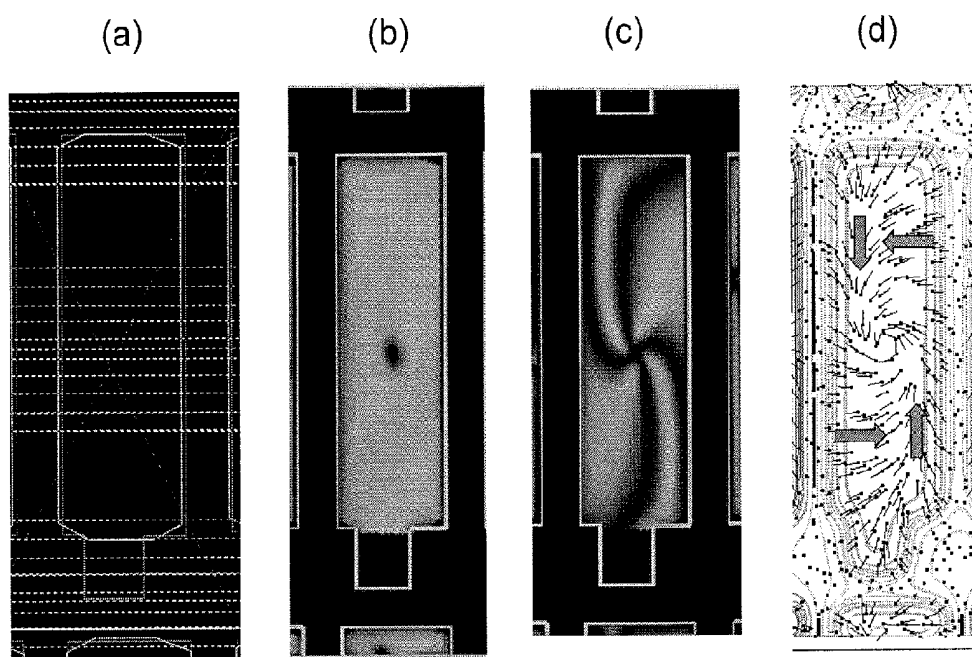


FIG. 13



(e)
EXAMPLE 2 (400ppi)

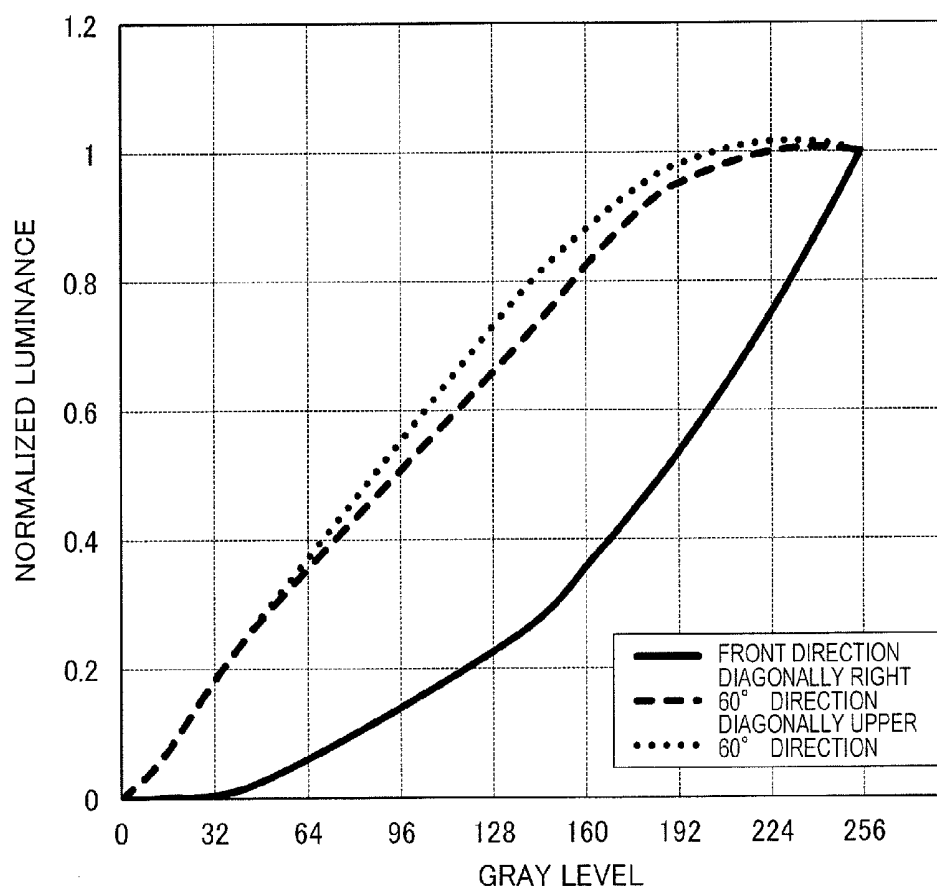
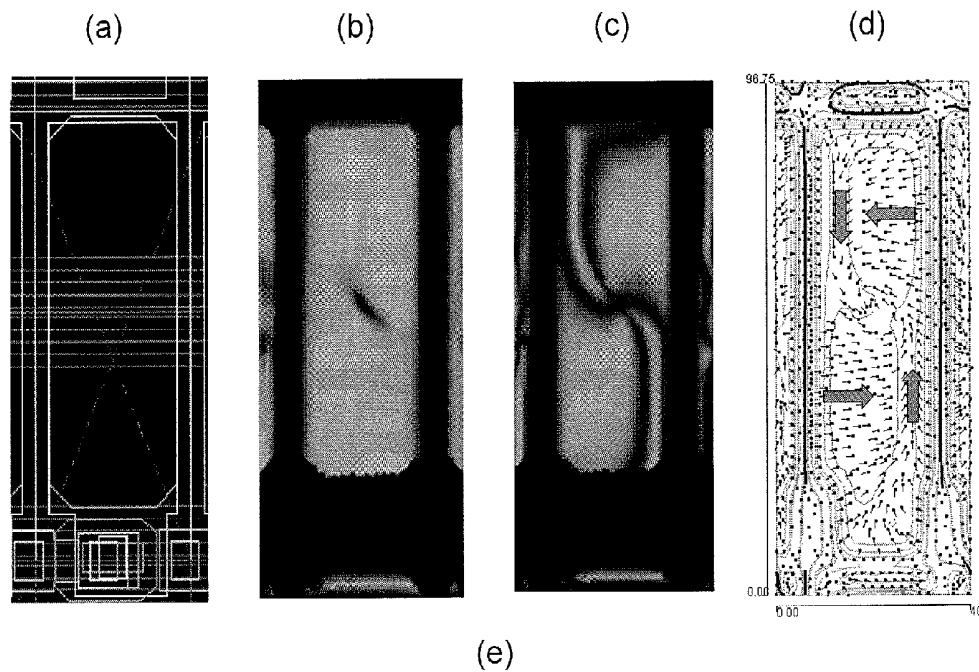


FIG.14



EXAMPLE 3 (300ppi)

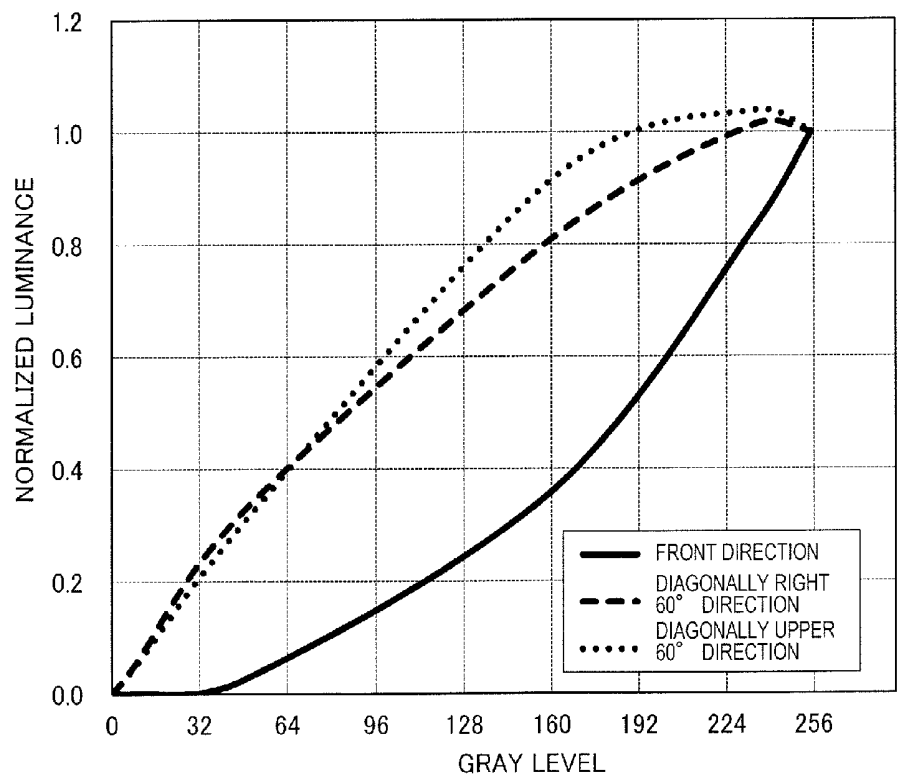
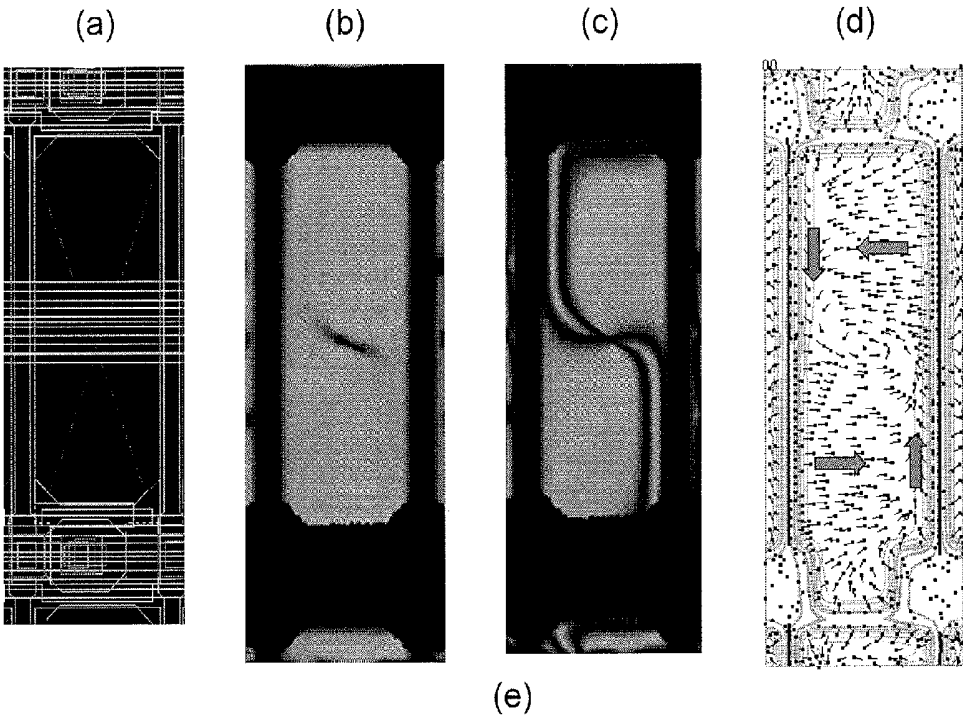


FIG. 15



EXAMPLE 4 (217ppi)

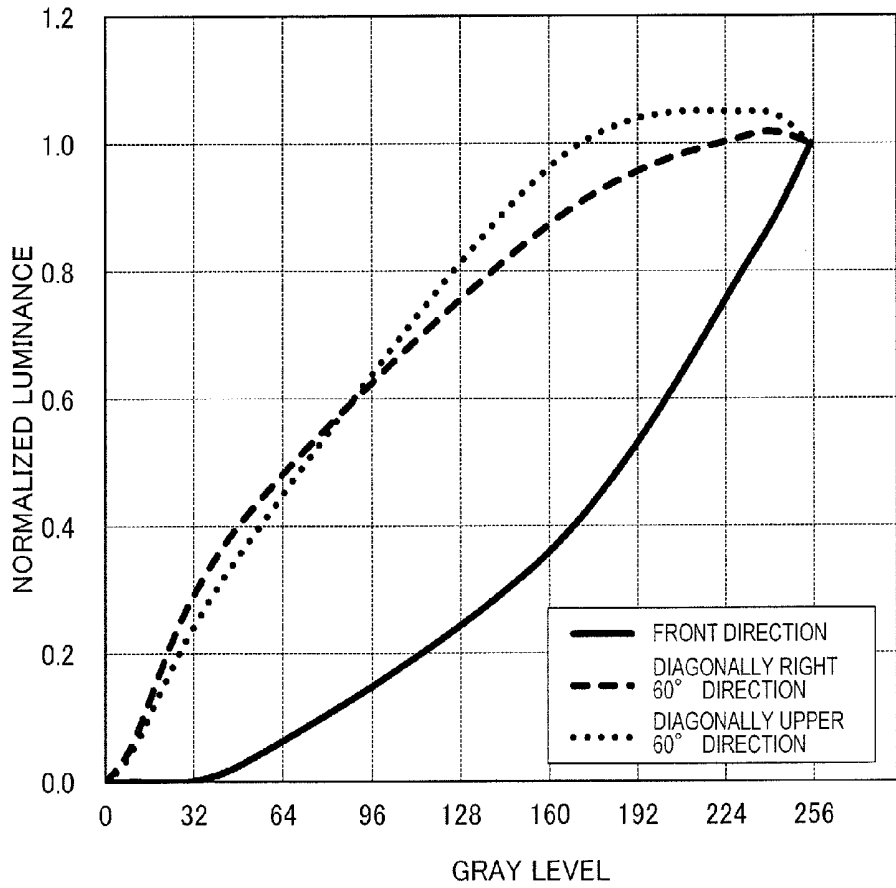
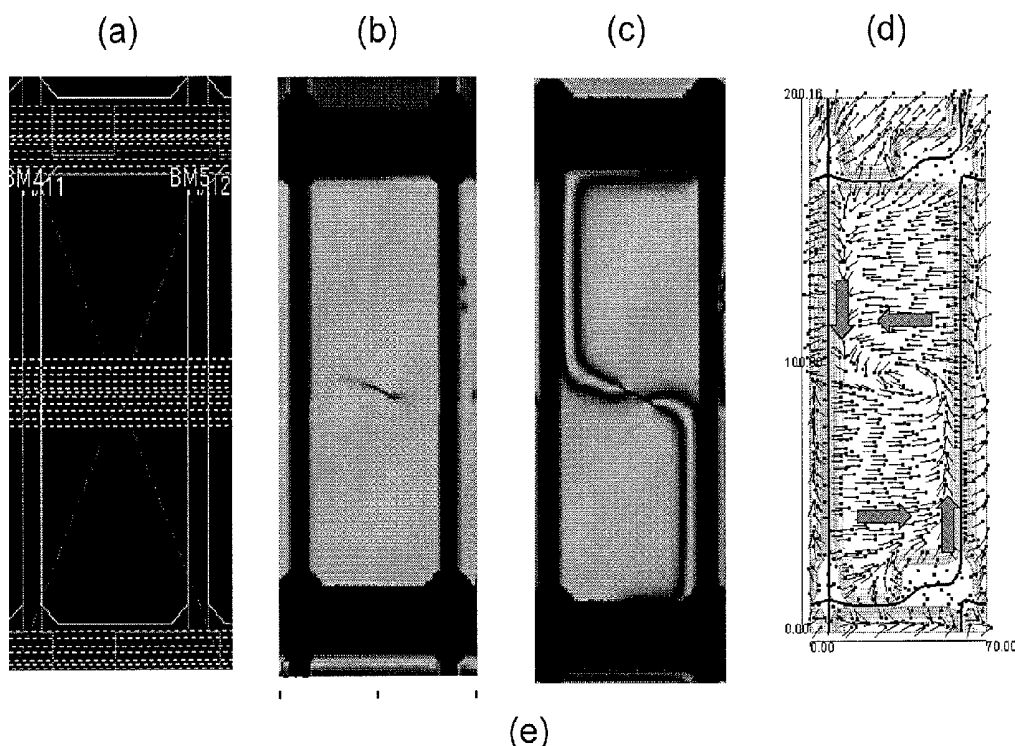


FIG. 16



EXAMPLE 5 (160ppi)

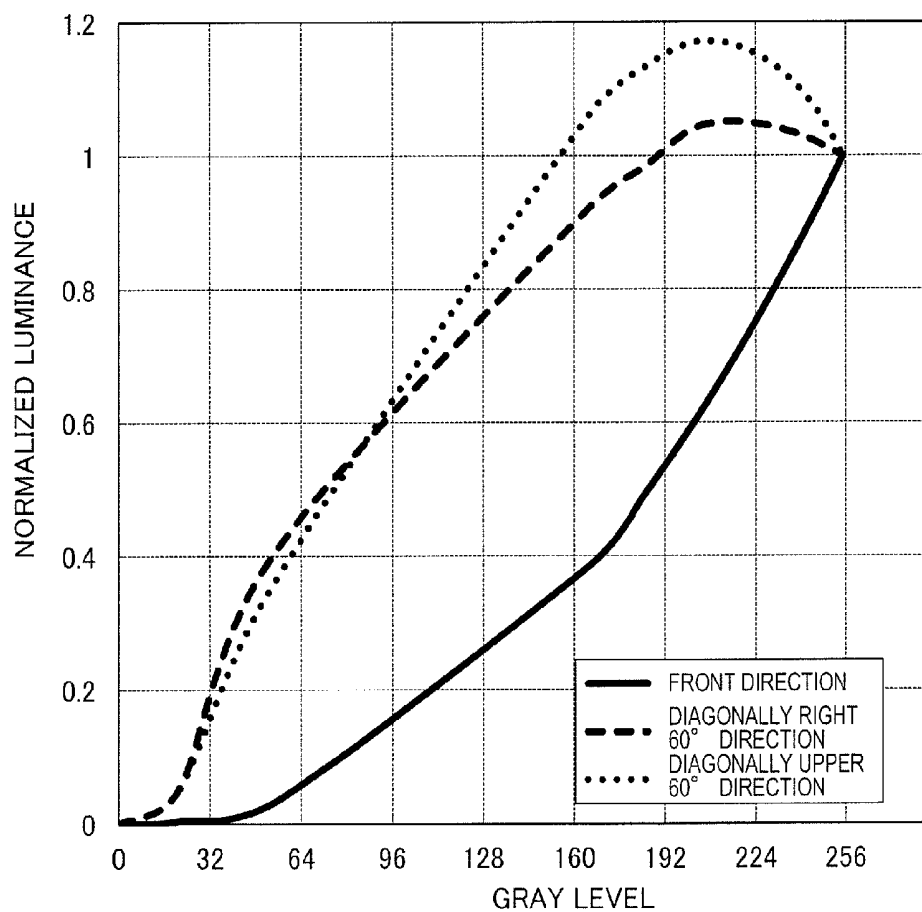
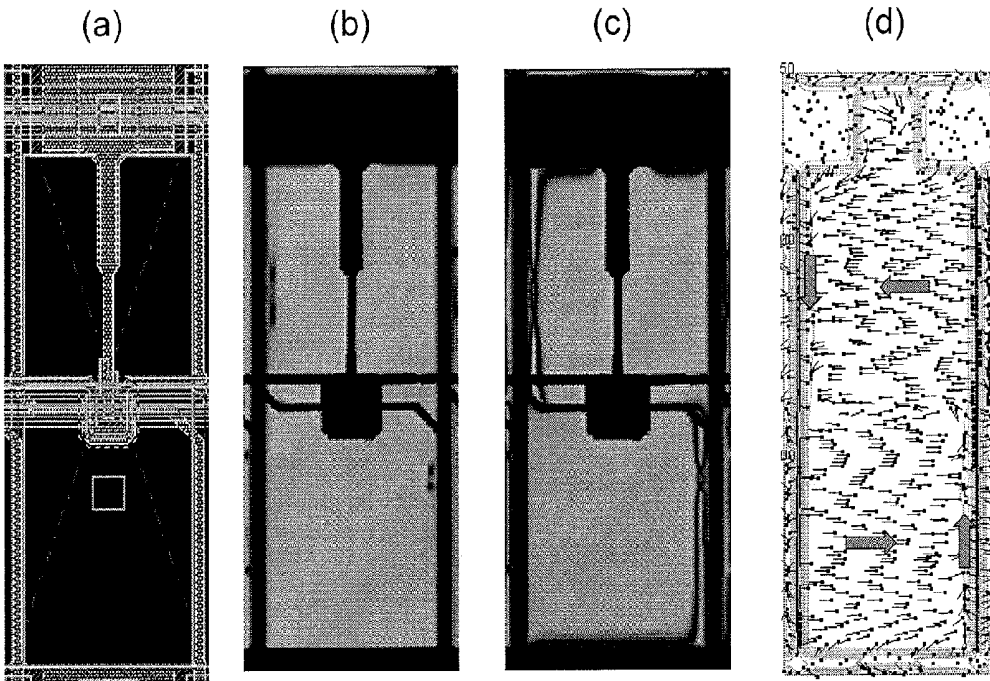


FIG. 17



(e)

EXAMPLE 6 (96ppi)

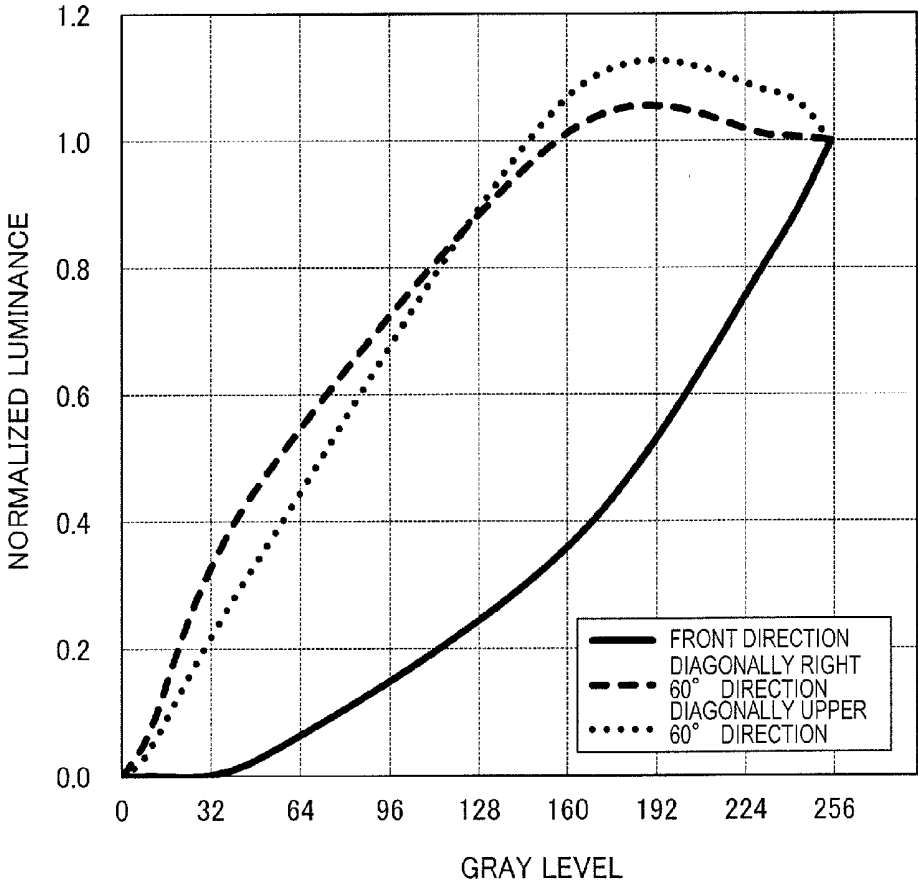
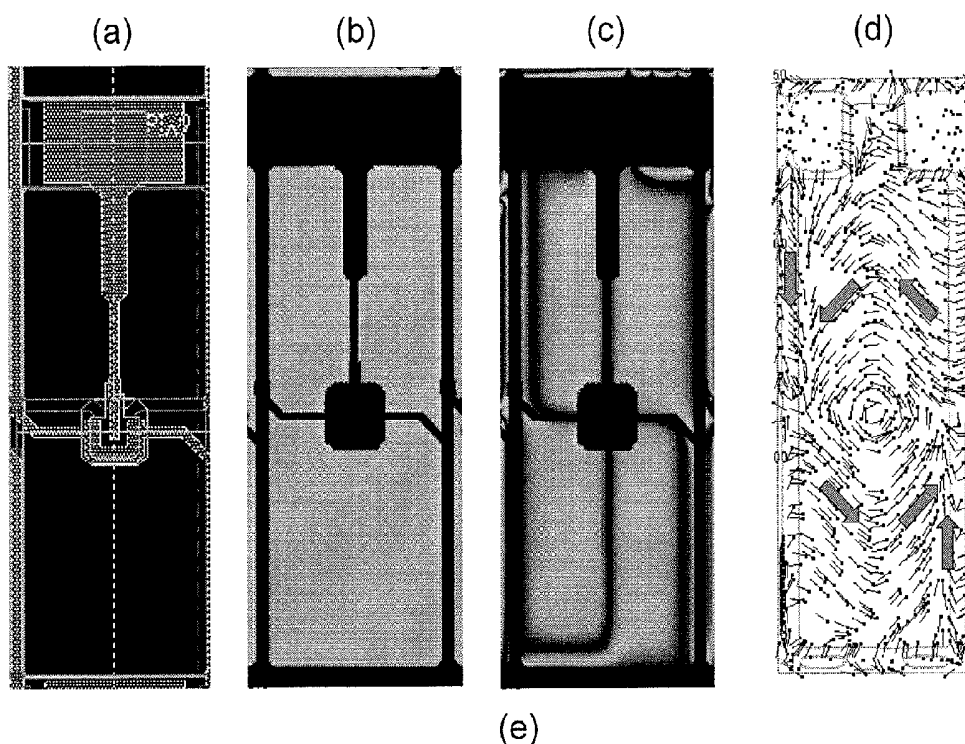


FIG. 18



COMPARATIVE EXAMPLE 1 (96ppi)

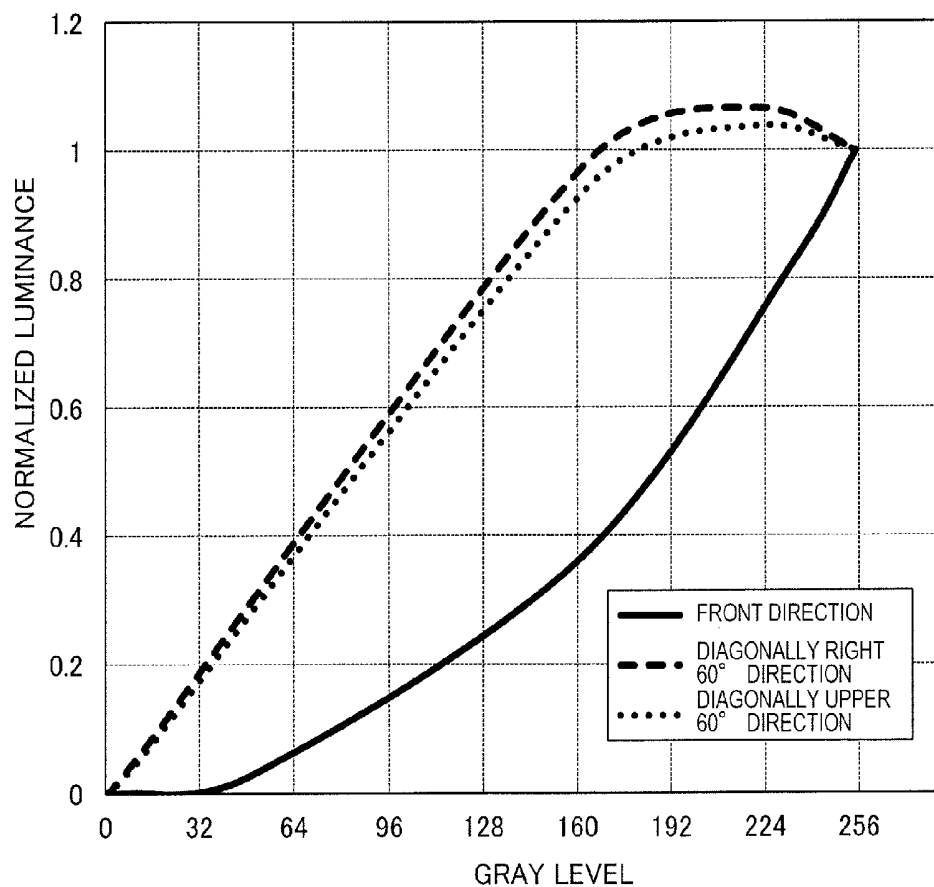


FIG. 19

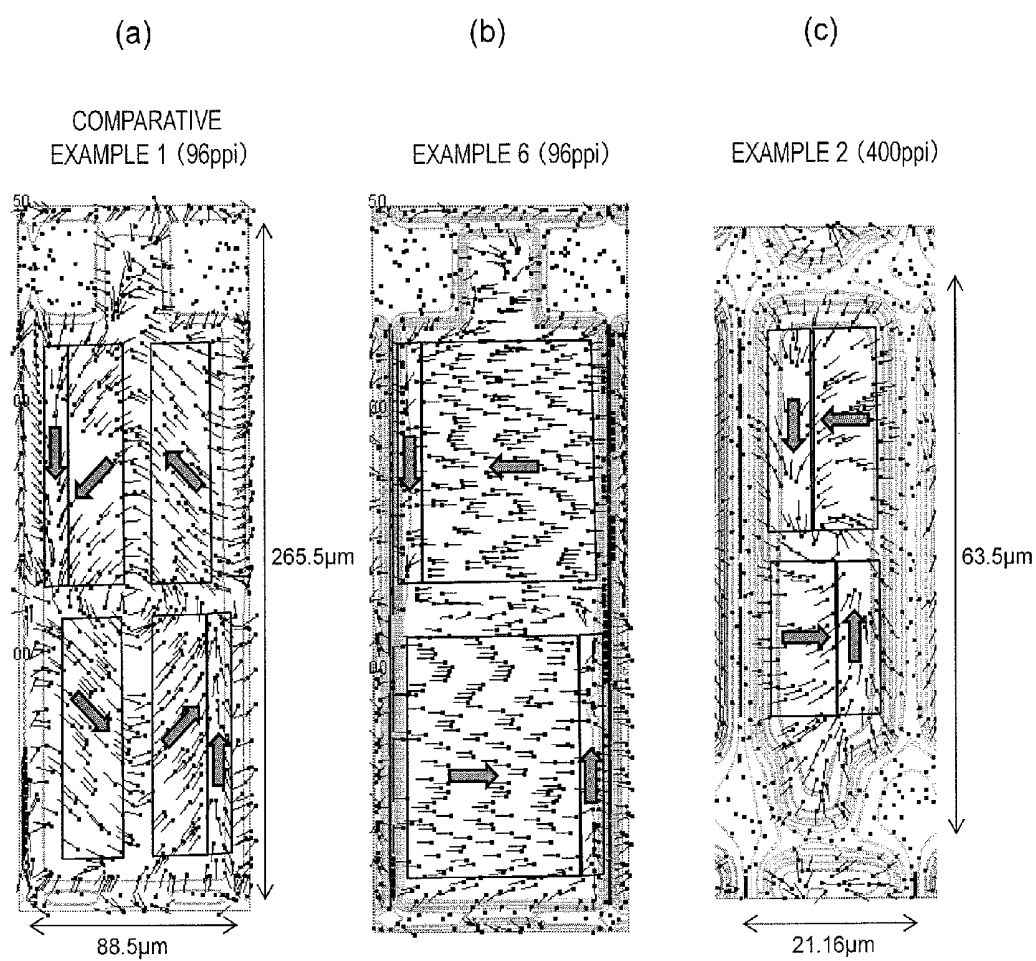


FIG. 20

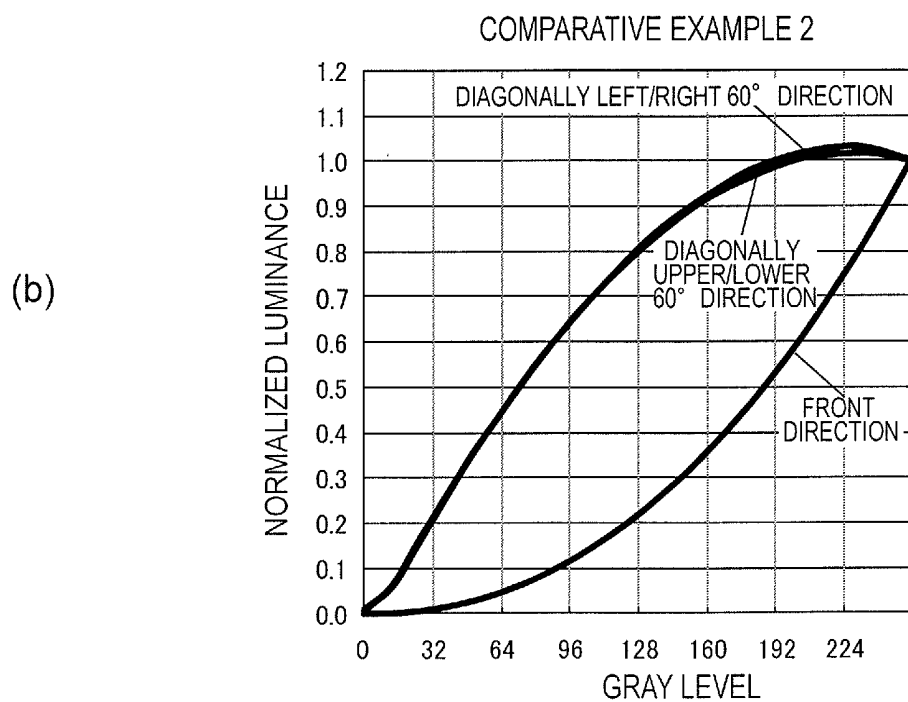
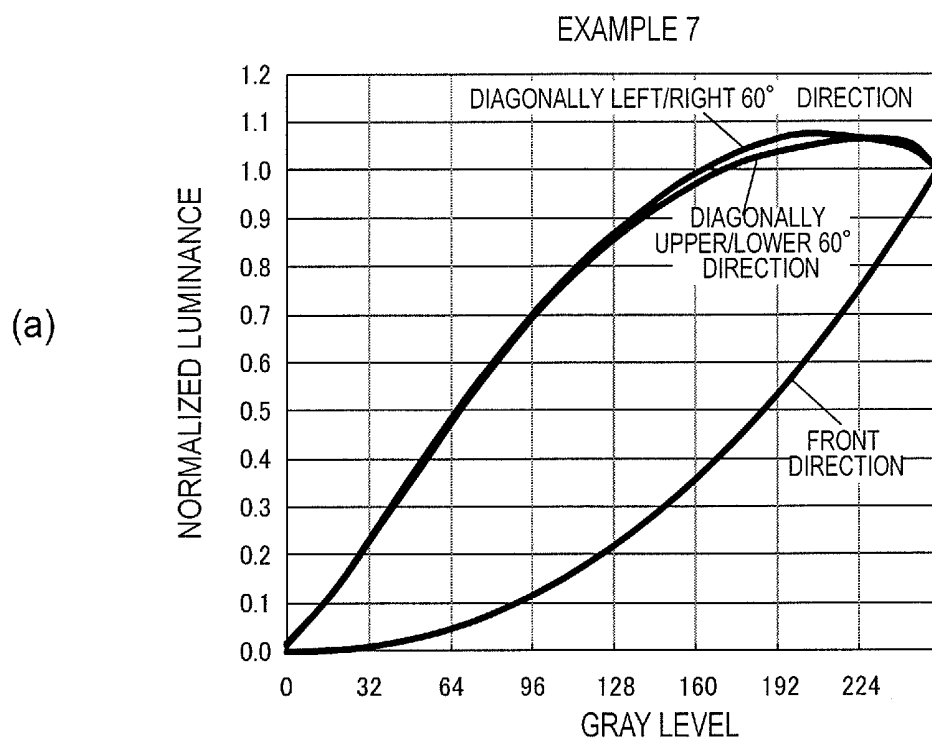


FIG. 21

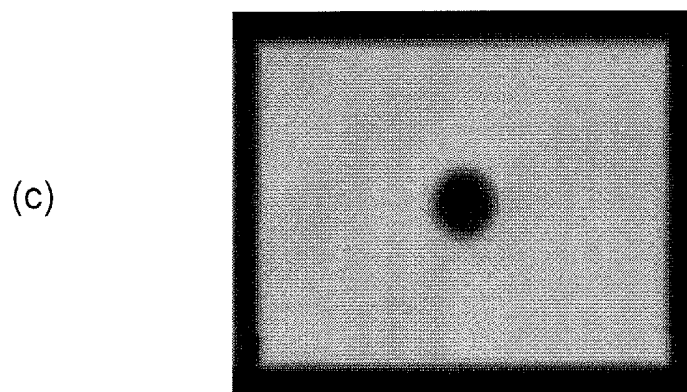
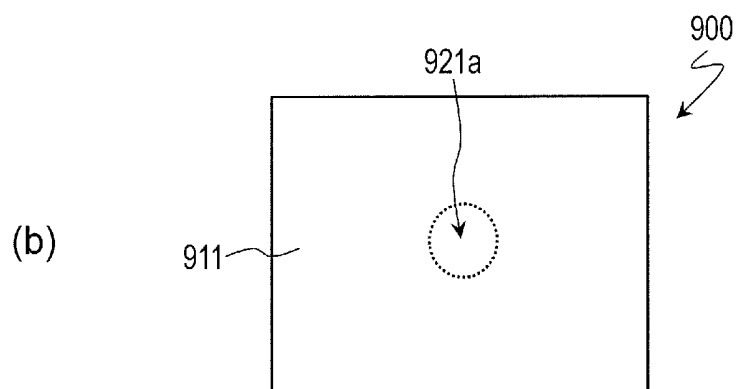
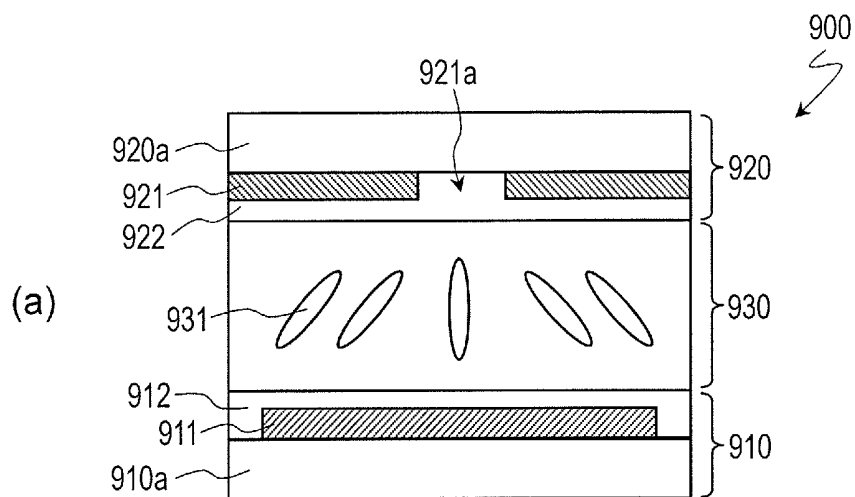


FIG. 22

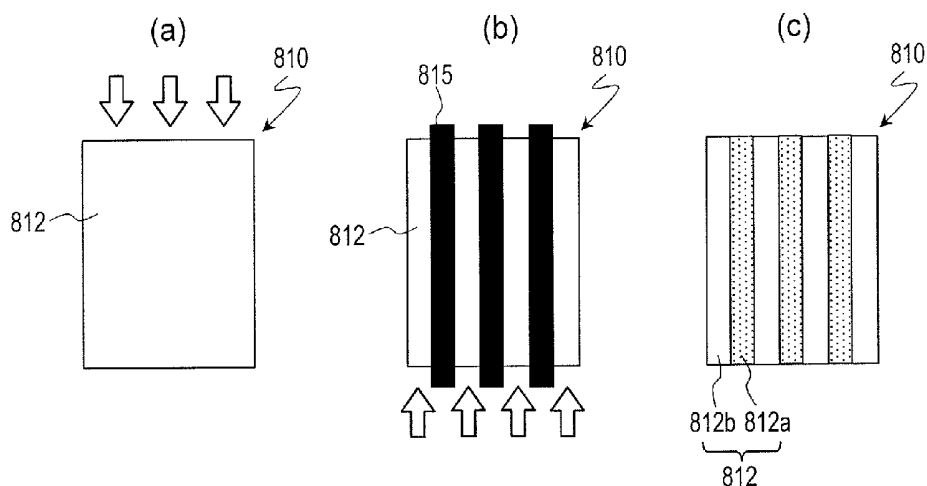


FIG. 23

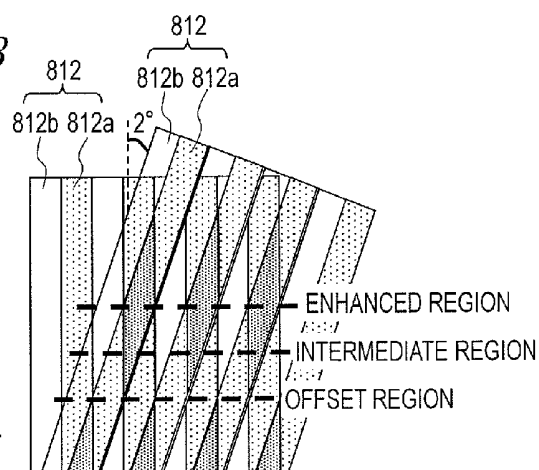


FIG. 24

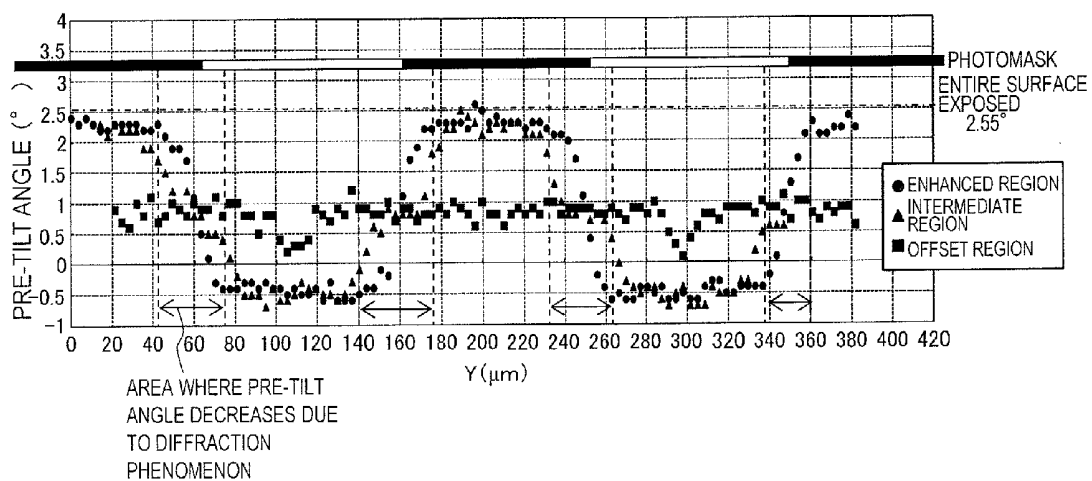


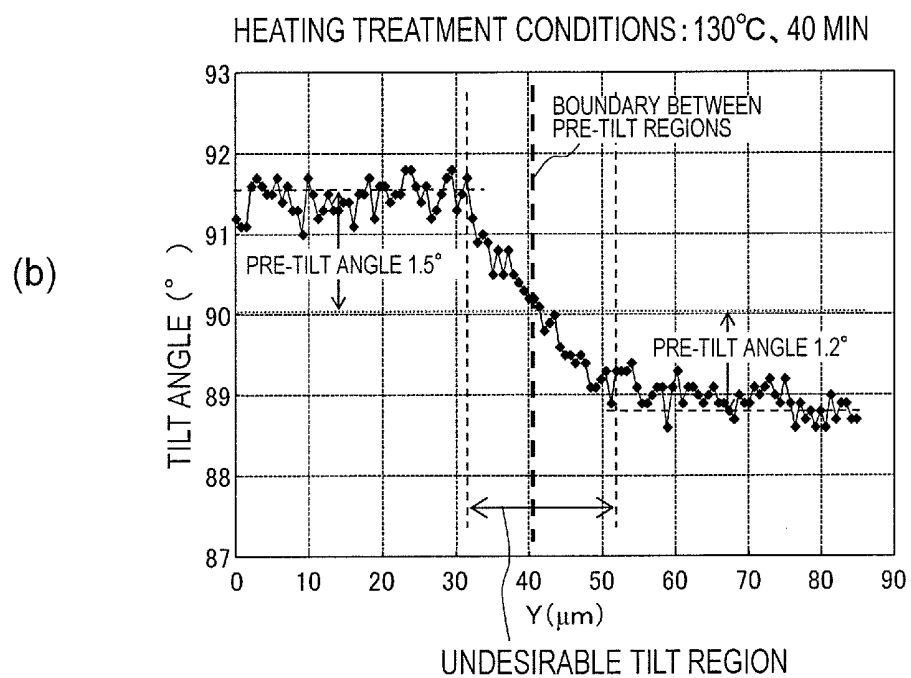
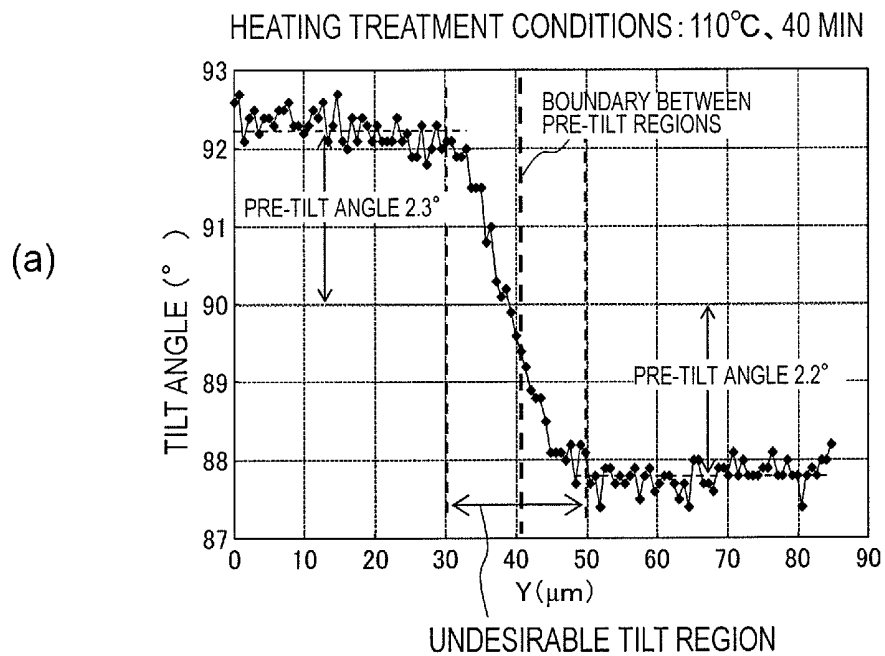
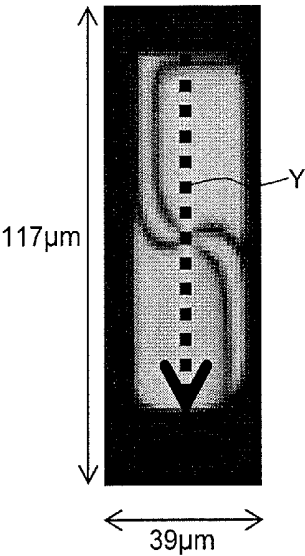
FIG. 25

FIG.26



LIQUID CRYSTAL DISPLAY DEVICE AND METHOD FOR MANUFACTURING SAME

TECHNICAL FIELD

[0001] The present invention relates to a liquid crystal display device, and particularly to a liquid crystal display device including a liquid crystal layer of a vertical alignment type, wherein the pre-tilt direction of liquid crystal molecules is defined by a photo-alignment film. The present invention also relates to a method for manufacturing a liquid crystal display device.

BACKGROUND ART

[0002] In recent years, liquid crystal display devices, whose display characteristics have improved, are more and more used in television receivers, or the like. Although viewing angle characteristics of liquid crystal display devices have improved, there is a demand for further improvements. Particularly, there is a strong demand for improving viewing angle characteristics of liquid crystal display devices using a liquid crystal layer of a vertical alignment type (referred to also as liquid crystal display devices of a VA mode).

[0003] At present, liquid crystal display device of a VA mode, which are used in large-size liquid crystal display devices such as televisions, employ an alignment-divided structure in which a plurality of liquid crystal domains are formed in one pixel in order to improve the viewing angle characteristic. A mainstream method for forming an alignment-divided structure is the MVA mode. The MVA mode is disclosed in Patent Document No. 1, for example.

[0004] In the MVA mode, by providing an alignment regulating structure on the liquid crystal layer side of each of a pair of substrates that are opposing each other with a vertical alignment-type liquid crystal layer interposed therebetween, there are formed a plurality of liquid crystal domains of different orientation directions (tilt directions) (typically of four different orientation directions) within each pixel. The alignment regulating structure may be slits (openings) or ribs (projecting structures) provided on electrodes, exerting alignment regulating forces from both sides of the liquid crystal layer.

[0005] Using slits and ribs, however, the alignment regulating force acting on liquid crystal molecules becomes non-uniform, thereby resulting in a distribution of response speed, because slits or ribs are linear, as opposed to cases where the pre-tilt direction is defined by an alignment film as in the conventional TN mode. Moreover, the display luminance lowers because the light transmittance lowers in areas where slits or ribs are provided.

[0006] In order to avoid such a problem, it is preferred to form an alignment-divided structure by defining the pre-tilt direction using an alignment film, also with liquid crystal display devices of a VA mode. A liquid crystal display device of the VA mode, in which an alignment-divided structure is formed as described above, has been proposed in Patent Document No. 2 by the present applicant.

[0007] In the liquid crystal display device disclosed in Patent Document No. 2, the pre-tilt direction is defined by an alignment film, thereby forming a 4-divided alignment structure. That is, in the presence of a voltage applied across the liquid crystal layer, there are formed four liquid crystal domains within one pixel. Such a 4-divided alignment structure may also be referred to simply as a 4D structure.

[0008] In the liquid crystal display device disclosed in Patent Document No. 2, the pre-tilt direction defined by one of a pair of alignment films that are opposing each other with a liquid crystal layer interposed therebetween is generally 90° apart from that of the other alignment film. Therefore, the liquid crystal molecules assume a twisted orientation in the presence of an applied voltage. The VA mode, in which the liquid crystal molecules assume a twisted orientation due to the use of a pair of vertical alignment films provided so that their pre-tilt directions (alignment treatment directions) are orthogonal to each other as described above, may be referred to also as the VATN (Vertical Alignment Twisted Nematic) mode or the RTN (Reverse Twisted Nematic) mode. As already described above, since a 4D structure is formed by the liquid crystal display device of Patent Document No. 2, the present applicant refers to the display mode of the liquid crystal display device of Patent Document No. 2 as the 4D-RTN mode.

[0009] As a specific method for allowing the pre-tilt direction of the liquid crystal molecules to be defined by an alignment film, methods in which a photo-alignment treatment is performed as described in Patent Document No. 2 have been considered promising. Since the photo-alignment treatment can be done with no direct contact, no static electricity will occur due to friction as in a rubbing treatment, and it is possible to improve the production yield. Patent Document No. 3 also discloses a liquid crystal display device of the VATN mode using an alignment film (photo-alignment film) having been subjected to a photo-alignment treatment.

CITATION LIST

Patent Literature

- [0010]** [Patent Document No. 1] Japanese Laid-Open Patent Publication No. 11-242225
[0011] [Patent Document No. 2] International Publication WO2006/132369
[0012] [Patent Document No. 3] International Publication WO2006/121220

SUMMARY OF INVENTION

Technical Problem

[0013] In recent years, however, the definition of the liquid crystal display device has increased, and a study by the present inventors has indicated that a display defect may occur (particularly, while playing a movie), if a VAIN mode using a photo-alignment film is employed for a high-definition liquid crystal display device. Specifically, it has been found that with high-definition pixel designs for medium- to small-size applications, the stability of the orientation of liquid crystal molecules or the response speed thereof may be insufficient.

[0014] The present invention, which has been made in view of the problems set forth above, has an object to provide a liquid crystal display device of the VA mode which is suitable for higher definitions and in which the pre-tilt direction of the liquid crystal molecules is defined by a photo-alignment film.

Solution to Problem

[0015] A liquid crystal display device in one embodiment of the present invention is a liquid crystal display device including a plurality of pixels arranged in a matrix pattern, the

liquid crystal display device including: a first substrate and a second substrate arranged so as to oppose each other; and a liquid crystal layer of a vertical alignment type provided between the first substrate and the second substrate, wherein: the first substrate includes a pixel electrode provided in each of the plurality of pixels, and a first photo-alignment film provided between the pixel electrode and the liquid crystal layer; the second substrate includes a counter electrode opposing the pixel electrode, and a second photo-alignment film provided between the counter electrode and the liquid crystal layer; the first photo-alignment film has, in each of the plurality of pixels, a first pre-tilt region defining a first pre-tilt direction, and a second pre-tilt region defining a second pre-tilt direction, which is anti-parallel to the first pre-tilt direction; the second photo-alignment film has, in each of the plurality of pixels, a third pre-tilt region defining a third pre-tilt direction, and a fourth pre-tilt region defining a fourth pre-tilt direction, which is anti-parallel to the third pre-tilt direction; and as seen from a display plane normal direction, an entire boundary between the first pre-tilt region and the second pre-tilt region of the first photo-alignment film and an entire boundary between the third pre-tilt region and the fourth pre-tilt region of the second photo-alignment film are aligned with each other.

[0016] In one embodiment, as seen from the display plane normal direction, the first pre-tilt region of the first photo-alignment film and the third pre-tilt region of the second photo-alignment film are aligned with each other and the second pre-tilt region of the first photo-alignment film and the fourth pre-tilt region of the second photo-alignment film are aligned with each other; and the third pre-tilt direction is anti-parallel to the first pre-tilt direction, and the fourth pre-tilt direction is anti-parallel to the second pre-tilt direction.

[0017] In one embodiment, an outer perimeter of the pixel electrode includes a first edge portion and a second edge portion; a direction which is orthogonal to the first edge portion and which extends toward inside of the pixel electrode is opposite to the first pre-tilt direction; and a direction which is orthogonal to the second edge portion and which extends toward inside of the pixel electrode is opposite to the second pre-tilt direction.

[0018] In one embodiment, when a voltage is applied between the pixel electrode and the counter electrode, four liquid crystal domains are formed in the liquid crystal layer in each of the plurality of pixels; and azimuth directions of four directors representing orientation directions of liquid crystal molecules included in the four liquid crystal domains, respectively, are different from each other.

[0019] In one embodiment, the four liquid crystal domains include: a first liquid crystal domain where the azimuth direction of the director is a first azimuth direction; a second liquid crystal domain where the azimuth direction of the director is a second azimuth direction; a third liquid crystal domain where the azimuth direction of the director is a third azimuth direction; and a fourth liquid crystal domain where the azimuth direction of the director is a fourth azimuth direction, wherein the difference between any two of the first azimuth direction, the second azimuth direction, the third azimuth direction and the fourth azimuth direction is generally equal to an integer multiple of 90° .

[0020] In one embodiment, assuming that the azimuth angle in the horizontal direction on the display plane is 0° , the first azimuth direction is generally 0° , generally 90° , generally 180° or generally 270° .

[0021] In one embodiment, the liquid crystal display device further includes a pair of linear polarizers which are arranged so as to oppose each other with the liquid crystal layer interposed therebetween and so that transmission axes thereof are generally orthogonal to each other, wherein the transmission axes of the pair of linear polarizers form an angle of generally 45° with respect to the first pre-tilt direction.

[0022] In one embodiment, the liquid crystal display device further includes a pair of circular polarizers opposing each other with the liquid crystal layer interposed therebetween.

[0023] In one embodiment, the liquid crystal layer includes liquid crystal molecules having a negative dielectric anisotropy.

[0024] In one embodiment, a shorter one of a pixel pitch along a display plane horizontal direction and a pixel pitch along a display plane vertical direction is $42\ \mu\text{m}$ or less.

[0025] In one embodiment, a screen resolution is 200 ppi or more.

[0026] A method for manufacturing a liquid crystal display device in one embodiment of the present invention is a method for manufacturing a liquid crystal display device including a plurality of pixels arranged in a matrix pattern, the liquid crystal display device including: a first substrate and a second substrate arranged so as to oppose each other; and a liquid crystal layer of a vertical alignment type provided between the first substrate and the second substrate, wherein the first substrate includes a pixel electrode provided in each of the plurality of pixels, and a first photo-alignment film provided between the pixel electrode and the liquid crystal layer; and the second substrate includes a counter electrode opposing the pixel electrode, and a second photo-alignment film provided between the counter electrode and the liquid crystal layer, the method including: a step (A) of forming, through a photo-alignment treatment, in each of regions of the first photo-alignment film corresponding to the plurality of pixels, a first pre-tilt region defining a first pre-tilt direction and a second pre-tilt region defining a second pre-tilt direction, which is anti-parallel to the first pre-tilt direction; a step (B) of forming, through a photo-alignment treatment, in each of regions of the second photo-alignment film corresponding to the plurality of pixels, a third pre-tilt region defining a third pre-tilt direction and a fourth pre-tilt region defining a fourth pre-tilt direction, which is anti-parallel to the third pre-tilt direction; a step (C) of attaching the first substrate and the second substrate with each other, after the step (A) and the step (B), wherein the step (A) and the step (B) are carried out so that when the first substrate and the second substrate are attached together in the step (C), an entire boundary between the first pre-tilt region and the second pre-tilt region of the first photo-alignment film and an entire boundary between the third pre-tilt region and the fourth pre-tilt region of the second photo-alignment film are aligned with each other as seen from a display plane normal direction.

[0027] In one embodiment, the method for manufacturing a liquid crystal display device further includes a step (D) of subjecting the liquid crystal layer to a re-alignment treatment including a heating treatment, after the step (C), wherein the heating treatment is performed at 110°C . or less.

Advantageous Effects of Invention

[0028] According to an embodiment of the present invention, there is provided a liquid crystal display device of a VA mode which is suitable for higher-definition applications, and

in which the pre-tilt direction of liquid crystal molecules is defined by a photo-alignment film.

BRIEF DESCRIPTION OF DRAWINGS

[0029] FIG. 1 A cross-sectional view schematically showing a liquid crystal display device 100 according to an embodiment of the present invention.

[0030] FIG. 2 A diagram showing an alignment-divided structure of a pixel 1001 in a liquid crystal display device of a 4D-RTN mode.

[0031] FIGS. 3 (a), (b) and (c) are diagrams illustrating a method for obtaining the alignment-divided structure of the pixel 1001 shown in FIG. 2.

[0032] FIG. 4 A diagram showing an alignment-divided structure of a pixel 1 in the liquid crystal display device 100.

[0033] FIGS. 5 (a), (b) and (c) are diagrams illustrating a method for obtaining the alignment-divided structure of the pixel 1 shown in FIG. 4.

[0034] FIG. 6 A diagram schematically showing liquid crystal domains to be formed when taking into consideration only the alignment regulating forces of a first photo-alignment film 12 and a second photo-alignment film 22.

[0035] FIG. 7 (a) to (d) are views illustrating the results of an orientation simulation for verifying the orientation of the liquid crystal molecules in the presence of an applied voltage, for a pixel 1001 of a common 4D-RTN mode.

[0036] FIG. 8 (a) to (d) are views illustrating the results of an orientation simulation for verifying the orientation of the liquid crystal molecules in the presence of an applied voltage for a pixel 1 of the liquid crystal display device 100.

[0037] FIG. 9 A diagram illustrating the reason why four liquid crystal domains are formed in a pixel 1 of the liquid crystal display device 100.

[0038] FIGS. 10 (a) and (b) are diagrams illustrating the reason why four liquid crystal domains are formed in a pixel 1 of the liquid crystal display device 100.

[0039] FIGS. 11 (a), (b) and (c) are diagrams illustrating the reason why four liquid crystal domains are formed in a pixel 1 of the liquid crystal display device 100.

[0040] FIG. 12 (a) to (e) are views illustrating the results of an orientation simulation and an optical simulation of Example 1.

[0041] FIG. 13 (a) to (e) are views illustrating the results of an orientation simulation and an optical simulation of Example 2.

[0042] FIG. 14 (a) to (e) are views illustrating the results of an orientation simulation and an optical simulation of Example 3.

[0043] FIG. 15 (a) to (e) are views illustrating the results of an orientation simulation and an optical simulation of Example 4.

[0044] FIG. 16 (a) to (e) are views illustrating the results of an orientation simulation and an optical simulation of Example 5.

[0045] FIG. 17 (a) to (e) are views illustrating the results of an orientation simulation and an optical simulation of Example 6.

[0046] FIG. 18 (a) to (e) are views illustrating the results of an orientation simulation and an optical simulation of Comparative Example 1.

[0047] FIGS. 19 (a), (b) and (c) are views, for Comparative Example 1, Example 6 and Example 2, respectively, each showing the orientation distribution within a pixel.

[0048] FIGS. 20 (a) and (b) are graphs, for Example 7 and Comparative Example 2, respectively, each showing the relationship between the gray level and the luminance (normalized luminance) when observed from the front direction, that when observed from a diagonally left/right 60° direction, and that when observed from a diagonally upper/lower 60° direction.

[0049] FIGS. 21 (a) and (b) are a cross-sectional view and a plan view, respectively, schematically showing one pixel of a liquid crystal display device 900 of a CPA mode, and (c) is a view showing the simulation results for the transmittance when a white voltage is applied across a liquid crystal layer 930 of the liquid crystal display device 900.

[0050] FIGS. 22 (a), (b) and (c) are diagrams showing the results of verifying the formation of an undesirable tilt region NGR due to the optical diffraction phenomenon.

[0051] FIG. 23 A diagram illustrating the results of verifying the formation of the undesirable tilt region NGR due to the optical diffraction phenomenon.

[0052] FIG. 24 A graph showing the position profile along the direction Y of the pre-tilt angle (the left-right direction of FIG. 23) for the enhanced region, the intermediate region and the offset region.

[0053] FIGS. 25 (a) and (b) are graphs, for two liquid crystal display device 100 prototyped as Example 7, each showing the distribution of the pre-tilt angle within a pixel 1.

[0054] FIG. 26 An optical microscope image of one pixel 1 of Example 7.

DESCRIPTION OF EMBODIMENTS

[0055] Embodiments of the present invention will be described with reference to the drawings. Note that the present invention is not limited to the following embodiments.

[0056] FIG. 1 shows a liquid crystal display device 100 of the present embodiment. FIG. 1 is a cross-sectional view schematically showing the liquid crystal display device 100.

[0057] As shown in FIG. 1, the liquid crystal display device 100 includes an active matrix substrate (first substrate) 10 and a counter substrate (second substrate) 20 arranged so as to oppose each other, and a liquid crystal layer 30 provided between the active matrix substrate 10 and the counter substrate 20. The liquid crystal display device 100 further includes a plurality of pixels arranged in a matrix pattern. Typically, the plurality of pixels include red pixels for displaying red, green pixels for displaying green, and blue pixels for displaying blue, and three pixels (a red pixel, a green pixel and a blue pixel) together form one color display pixel.

[0058] An active matrix substrate (referred to also as a “TFT substrate”) 10 includes a pixel electrode 11 provided in each of the plurality of pixels, and a first photo-alignment film 12 provided between the pixel electrode 11 and the liquid crystal layer 30. The pixel electrode 11 and the first photo-alignment film 12 are supported on an insulative transparent substrate (e.g., a glass substrate) 10a. Although not shown in the figures, the active matrix substrate includes a thin film transistor (TFT) electrically connected to the pixel electrode 11, a scanning line (gate bus line) for supplying a scanning signal to a TFT, a signal line (source bus line) for supplying a display signal to a TFT, etc.

[0059] The counter substrate (referred to also as a “color filter substrate”) 20 includes a counter electrode 21 opposing the pixel electrode 11, and the second photo-alignment film 22 provided between the counter electrode 21 and the liquid

crystal layer **30**. The counter electrode **21** and the second photo-alignment film **22** are supported on an insulative transparent substrate (e.g., a glass substrate) **20a**. Although not shown in the figures, the counter substrate **20** includes a color filter layer. Typically, the color filter layer includes red color filters provided so as to correspond to red pixels, green color filters provided so as to correspond to green pixels, and blue color filters provided so as to correspond to blue pixels.

[0060] The liquid crystal layer **30** is a liquid crystal layer of a vertical alignment type, including liquid crystal molecules **31** having a negative dielectric anisotropy. In the absence of a voltage applied across the liquid crystal layer **30**, the liquid crystal molecules **31** are oriented generally vertical to the substrate surface, as shown in FIG. 1.

[0061] The liquid crystal display device **100** further includes a pair of linear polarizers **18** and **28** opposing each other with at least the liquid crystal layer **30** interposed therebetween. The linear polarizers **18** and **28** are arranged so that their transmission axes are generally orthogonal to each other. That is, the linear polarizers **18** and **28** are arranged in a cross-Nicol arrangement. Note that a pair of circular polarizers may be provided instead of the pair of linear polarizers **18** and **28**. That is, light to be incident on the liquid crystal layer **30** may be either linearly-polarized light or circularly-polarized light.

[0062] The first photo-alignment film **12** and the second photo-alignment film **22** are each a vertical alignment film having been subjected to a photo-alignment treatment, and define the pre-tilt direction of the liquid crystal molecules **31**. The first photo-alignment film **12** has two regions, within each pixel, defining different pre-tilt directions from each other. Similarly, the second photo-alignment film **22** has two regions, within each pixel, defining different pre-tilt directions from each other.

[0063] The alignment-divided structure formed by the first photo-alignment film **12** and the second photo-alignment film **22** of the liquid crystal display device **100** of the present embodiment will be described below, following the description of the alignment-divided structure of the 4D-RTN mode as disclosed in Patent Document No. 2 and Patent Document No. 3.

[0064] FIG. 2 shows an alignment-divided structure of a pixel **1001** in a liquid crystal display device of a common 4D-RTN mode. In the presence of a voltage applied across the liquid crystal layer, four liquid crystal domains A, B, C and D are formed in the pixel **1001** as shown in FIG. 2. The four liquid crystal domains A, B, C and D are arranged in a 2-by-2 matrix pattern.

[0065] The azimuth directions of the directors **t1**, **t2**, **t3** and **t4** of the liquid crystal domains A, B, C and D are four azimuth directions, of which the difference between any two directions is generally equal to an integer multiple of 90°. Each of the directors **t1**, **t2**, **t3** and **t4** is a representation of the orientation direction of the liquid crystal molecules included in the liquid crystal domain, and it in the 4D-RTN mode is the tilt direction of liquid crystal molecules in the vicinity of the center on the layer plane and in the thickness direction of the liquid crystal layer in the presence of a voltage applied across the liquid crystal layer. Each liquid crystal domain is characterized by the azimuth direction of the director (the tilt direction described above), and the azimuth direction of the director has a dominant influence on the viewing angle dependence of the domain.

[0066] Note that a pair of polarizers opposing each other with the liquid crystal layer interposed therebetween are arranged so that the transmission axes (polarization axes) are orthogonal to each other, and more specifically, they are arranged so that one transmission axis is parallel to the horizontal direction of the display plane, and the other transmission axis is parallel to the vertical direction to the display plane.

[0067] Assuming that the azimuth angle (the 3 o'clock direction) in the horizontal direction on the display plane is 0°, the azimuth direction of the director **t1** of the liquid crystal domain A is a generally 225° direction, the azimuth direction of the director **t2** of the liquid crystal domain B is a generally 315° direction, the azimuth direction of the director **t3** of the liquid crystal domain C is a generally 45° direction, and the azimuth direction of the director **t4** of the liquid crystal domain D is a generally 135° direction. That is, the liquid crystal domains A, B, C and D are arranged so that the azimuth directions of the directors are generally 90° apart from each other between adjacent liquid crystal domains.

[0068] Now, referring to FIGS. 3(a), (b) and (c), an alignment-dividing method for obtaining the alignment-divided structure of the pixel **1001** shown in FIG. 2 will be described. FIG. 3(a) shows pre-tilt directions PD1 and PD2 defined by the photo-alignment film provided on the active matrix substrate, and FIG. 3(b) shows pre-tilt directions PD3 and PD4 defined by the photo-alignment film provided on the counter substrate. FIG. 3(c) shows tilt directions (directors) in the presence of a voltage applied across the liquid crystal layer.

[0069] A region on the active matrix substrate side (a region corresponding to one pixel **1001**) is divided into two regions in the left-right direction, as shown in FIG. 3(a), and the photo-alignment treatment is performed so that the photo-alignment films (vertical alignment films) of these regions (the left region and the right region) define the pre-tilt directions PD1 and PD2 that are anti-parallel to each other. Here, the photo-alignment treatment is performed through diagonal irradiations of ultraviolet light from directions indicated by the arrows.

[0070] On the other hand, a region on the counter substrate side (a region corresponding to one pixel region **1001**) is divided into two regions in the up-down direction, as shown in FIG. 3(b), and the photo-alignment treatment is performed so that the photo-alignment films (vertical alignment films) of these regions (the upper region and the lower region) define the pre-tilt directions PD3 and PD4 that are anti-parallel to each other. Here, the photo-alignment treatment is performed through diagonal irradiations of ultraviolet light from directions indicated by the arrows.

[0071] A pixel **1001** that is alignment-divided as shown in FIG. 3(c) can be formed by attaching together an active matrix substrate and a counter substrate which have been subjected to a photo-alignment treatment as shown in FIGS. 3(a) and (b). As can be seen from FIGS. 3(a), (b) and (c), for each of the liquid crystal domains A to D, the pre-tilt direction defined by the photo-alignment film of the active matrix substrate and the pre-tilt direction defined by the photo-alignment film of the counter substrate are generally 90° apart from each other, so that a tilt direction (the azimuth direction of the director of the liquid crystal domain) is defined along an intermediate direction between these two pre-tilt directions.

[0072] As already described above, a display defect may occur (particularly, while playing a movie), if such an alignment-divided structure as that of the pixel **1001** (i.e., of a

common 4D-RTN mode) is employed in a high-definition liquid crystal display device. The reason for this will now be described.

[0073] When making an alignment-divided structure of the 4D-RTN mode, it is necessary to perform the exposure step twice for each of the photo-alignment film on the active matrix side and the photo-alignment film on the counter substrate side. The ultraviolet light irradiation is performed from different directions in the first exposure step and in the second exposure step. Where the exposure step is performed through a scanning exposure using a photomask, there will be a region where a sufficient pre-tilt angle cannot be realized (hereinafter referred to as an “undesirable tilt region”), due to the optical diffraction phenomenon, in the vicinity of an exposure boundary (the boundary between two regions where different pre-tilt directions are to be defined). Note that the “pre-tilt angle”, as used in the present specification, refers to the angle of the long axis of the liquid crystal molecules **31** with respect to the substrate surface normal direction in the absence of an applied voltage.

[0074] Specifically, the photo-alignment film on the active matrix substrate side will have an undesirable tilt region NGR1 in the vicinity of the boundary BD1 between the left region and the right region, as shown in FIG. 3(a). The photo-alignment film on the counter substrate side will have an undesirable tilt region NGR2 in the vicinity of the boundary BD2 between the upper region and the lower region, as shown in FIG. 3(b). Therefore, with the active matrix substrate and the counter substrate attached together, each pixel **1001** has a cross-shaped undesirable tilt region NGR, including a portion extending in the vertical direction (corresponding to the undesirable tilt region NGR1) and another portion extending in the horizontal direction (corresponding to the undesirable tilt region NGR2).

[0075] With high-definition pixel designs for medium- to small-size applications, the undesirable pre-tilt region accounts for a large proportion of the entire pixel **1001** since the pixel pitch is small. Therefore, the average pre-tilt angle of the entire pixel **1001** will be small, and the orientation of the liquid crystal molecules may become unstable and the response speed may be low (i.e., the response time may be long).

[0076] Then, the alignment-divided structure of a pixel in the liquid crystal display device **100** of the present embodiment will be described. FIG. 4 shows the alignment-divided structure of a pixel **1** in the liquid crystal display device **100**.

[0077] When a voltage is applied between the pixel electrode **11** and the counter electrode **21**, there are formed four liquid crystal domains A, B, C and D, in each pixel **1**, in the liquid crystal layer **30**, as shown in FIG. 4. The azimuth directions of the four directors **t1**, **t2**, **t3** and **t4** representing the orientation direction of the liquid crystal molecules **31** included in the four liquid crystal domains A, B, C and D, respectively, are different from each other.

[0078] Assuming that the azimuth angle (the 3 o'clock direction) in the horizontal direction on the display plane is 0°, the azimuth direction of the director **t1** of the liquid crystal domain A is a generally 270° direction, the azimuth direction of the director **t2** of the liquid crystal domain B is a generally 0° direction, the azimuth direction of the director **t3** of the liquid crystal domain C is a generally 90° direction, and the azimuth direction of the director **t4** of the liquid crystal domain D is a generally 180° direction. That is, the difference between any two of the azimuth directions of the four direc-

tors of the liquid crystal domains A, B, C and D is generally equal to an integer multiple of 90°.

[0079] The transmission axes (polarization axes) **P1** and **P2** of the pair of linear polarizers **18** and **28** each form an angle of generally 45° with respect to the azimuth directions of the directors **t1**, **t2**, **t3** and **t4** of the liquid crystal domains A, B, C and D. As will be understood from the description below, transmission axes **P1** and **P2** of the pair of linear polarizers **18** and **28** each also form an angle of generally 45° with respect to the pre-tilt direction defined by the first photo-alignment film **12** and the second photo-alignment film **22**.

[0080] Note that while FIG. 4 shows an example where the four liquid crystal domains A, B, C and D each account for an equal area within the pixel **1**, the areas the four liquid crystal domains A, B, C and D may not be equal to each other. Note however that in view of the uniformity of the viewing angle characteristic, it is preferred that the area difference between the four liquid crystal domains A, B, C and D is as small as possible, and specifically, it is preferred that the difference between the area of the largest one of the four liquid crystal domains A, B, C and D and the area of the smallest liquid crystal domain is 50% or less of the largest area. FIG. 4 shows an example of the most preferred (i.e., ideal) 4-divided structure in view of the viewing angle characteristic.

[0081] Referring now to FIGS. 5(a), (b) and (c), an alignment-dividing method for obtaining an alignment-divided structure of the pixel **1** in the liquid crystal display device **100** of the present embodiment will be described. FIG. 5(a) shows pre-tilt directions **PD1** and **PD2** defined by the first photo-alignment film **12** provided on the active matrix substrate **10**, and FIG. 5(b) shows pre-tilt directions **PD3** and **PD4** defined by the second photo-alignment film **22** provided on the counter substrate **20**. FIG. 5(c) shows tilt directions (directors) in the presence of a voltage applied across the liquid crystal layer **30**.

[0082] As shown in FIG. 5(a), the first photo-alignment film **12** includes, within each pixel **1**, a first pre-tilt region **12a** defining the first pre-tilt direction **PD1**, and a second pre-tilt region **12b** defining the second pre-tilt direction **PD2**, which is anti-parallel to the first pre-tilt direction **PD1**. Specifically, a region of the first photo-alignment film **12** corresponding to one pixel **1** is divided into two regions in the up-down direction, and the photo-alignment treatment is performed so that these regions (the first pre-tilt region and the second pre-tilt region) **12a** and **12b** define anti-parallel pre-tilt directions (the first pre-tilt direction and the second pre-tilt direction) **PD1** and **PD2**. Here, the photo-alignment treatment is performed through diagonal irradiations of ultraviolet light from directions indicated by the arrows.

[0083] On the other hand, the second photo-alignment film **22** includes, within each pixel **1**, a third pre-tilt region **22a** defining the third pre-tilt direction **PD3** and a fourth pre-tilt region **22b** defining the fourth pre-tilt direction **PD4**, which is anti-parallel to the third pre-tilt direction **PD3**, as shown in FIG. 5(b). Specifically, a region of the second photo-alignment film **22** corresponding to one pixel **1** is divided into two regions in the up-down direction, and the photo-alignment treatment is performed so that these regions (the second pre-tilt region and the third pre-tilt region) **22a** and **22b** define anti-parallel pre-tilt directions (the third pre-tilt direction and the fourth pre-tilt direction) **PD3** and **PD4**. Here, the photo-alignment treatment is performed through diagonal irradiations of ultraviolet light from directions indicated by the arrows. Note that with the active matrix substrate **10** and the

counter substrate **20** attached together, the third pre-tilt region **22a** of the second photo-alignment film **22** is aligned with (opposes) the first pre-tilt region **12a** of the first photo-alignment film **12**, and the fourth pre-tilt region **22b** of the second photo-alignment film **22** is aligned with (opposes) the second pre-tilt region **12b** of the first photo-alignment film **12**, as seen from the display plane normal direction. With the active matrix substrate **10** and the counter substrate **20** attached together, the third pre-tilt direction PD3 is anti-parallel to the first pre-tilt direction PD1, and the fourth pre-tilt direction PD4 is anti-parallel to the second pre-tilt direction PD2.

[0084] A pixel **1** that is alignment-divided as shown in FIG. 5(c) can be formed by attaching together the active matrix substrate **10** and the counter substrate **20** which have been subjected to a photo-alignment treatment as shown in FIGS. 5(a) and (b). Note that when taking into consideration only the alignment regulating force of the first photo-alignment film **12** and the second photo-alignment film **22** having been subjected to a photo-alignment treatment as shown in FIGS. 5(a) and (b), one may think that only two liquid crystal domains will be formed as in a pixel **1'** shown in FIG. 6 in the presence of an applied voltage. However, for reasons to be described below, there are actually formed the four liquid crystal domains A, B, C and D, as shown in FIG. 5(c).

[0085] There may be an undesirable tilt region NGR1, where a sufficient pre-tilt angle cannot be realized, in the vicinity of the boundary BD1 between the first pre-tilt region **12a** and the second pre-tilt region **12b** of the first photo-alignment film **12** (see FIG. 5(a)). There may be an undesirable tilt region NGR2, where a sufficient pre-tilt angle cannot be realized, in the vicinity of the boundary BD2 between the third pre-tilt region **22a** and the fourth pre-tilt region **22b** of the second photo-alignment film **22**. However, as shown in FIG. 5(c), in the liquid crystal display device **100** of the present embodiment, the entire boundary BD1 between the first pre-tilt region **12a** and the second pre-tilt region **12b** of the first photo-alignment film **12** and the entire boundary BD2 between the third pre-tilt region **22a** and the fourth pre-tilt region **22b** of the second photo-alignment film **22** are aligned with each other, as seen from the display plane normal direction. Thus, the undesirable tilt region NGR1 on the side of the first photo-alignment film **12** and the undesirable tilt region NGR2 on the side of the second photo-alignment film **22** are aligned with each other, thereby forming an undesirable tilt NGR extending only in the horizontal direction for the entire pixel **1**, as shown in FIG. 5(c).

[0086] Therefore, with the pixel **1** of the liquid crystal display device **100** of the present embodiment, the area of the undesirable tilt region NGR can be made smaller than that with the pixel **1001** shown in FIG. 3(c). Therefore, since the lowering of the average pre-tilt angle of the entire pixel **1** (due to the undesirable tilt region NGR) can be suppressed, it is possible to sufficiently stabilize the orientation of the liquid crystal molecules **31** and to realize a sufficient response speed.

[0087] Now, a method for manufacturing the liquid crystal display device **100** of the present embodiment will be described.

[0088] First, the active matrix substrate **10** having the first photo-alignment film **12** is prepared. This step can be carried out in a similar manner to that for manufacturing an active matrix substrate of a common 4D-RTN mode.

[0089] Next, a photo-alignment treatment is performed to form the first pre-tilt region **12a** defining the first pre-tilt

direction PD1 and the second pre-tilt region **12b** defining the second pre-tilt direction PD2, which is anti-parallel to the first pre-tilt direction PD1, within each of regions of the first photo-alignment film **12** corresponding to a plurality of pixels **1**. This step includes, for example, a step of irradiating with light a portion of the first photo-alignment film **12** to be the first pre-tilt region **12a** while a portion to be the second pre-tilt region **12b** is shaded with a photomask, and then irradiating with light the portion of the first photo-alignment film **12** to be the second pre-tilt region **12b** while the first pre-tilt region **12a** of the first photo-alignment film **12** is shaded with a photomask. Note that it is understood that a portion to be the second pre-tilt region **12b** may be irradiated with light before a portion to be the first pre-tilt region **12a** is irradiated with light.

[0090] On the other hand, the counter substrate **20** having the second photo-alignment film **22** is prepared, separately from the active matrix substrate **10**. This step can be carried out in a similar manner to that for producing a counter substrate of a common 4D-RTN mode.

[0091] Next, a photo-alignment treatment is performed to form the third pre-tilt region **22a** defining the third pre-tilt direction PD3 and the fourth pre-tilt region **22b** defining the fourth pre-tilt direction PD4, which is anti-parallel to the third pre-tilt direction PD3, within each of regions of the second photo-alignment film **22** corresponding to a plurality of pixels **1**. This step includes, for example, a step of irradiating with light a portion of the second photo-alignment film **22** to be the third pre-tilt region **22a** while a portion to be the fourth pre-tilt region **22b** is shaded with a photomask, and then irradiating with light the portion of the second photo-alignment film **22** to be the fourth pre-tilt region **22b** while the third pre-tilt region **22a** of the second photo-alignment film **22** is shaded with a photomask. Note that it is understood that a portion to be the fourth pre-tilt region **22b** may be irradiated with light before a portion to be the third pre-tilt region **22a** is irradiated with light.

[0092] Then, the active matrix substrate **10**, with the first pre-tilt region **12a** and the second pre-tilt region **12b** formed on the first photo-alignment film **12**, and the counter substrate **20**, with the third pre-tilt region **22a** and the fourth pre-tilt region **22b** formed on the second photo-alignment film **22**, are attached together.

[0093] Then, a vacuum injection method is used, for example, to inject a liquid crystal material into a gap between the active matrix substrate **10** and the counter substrate **20**, thereby forming the liquid crystal layer **30**. Note that it is understood that the liquid crystal layer **30** may be formed by a dripping method (i.e., applying a liquid crystal material on one of the substrates before the substrates are attached together).

[0094] The step of performing a photo-alignment treatment on the first photo-alignment film **12** and the step of performing a photo-alignment treatment on the second photo-alignment film **22** are carried out so that when the active matrix substrate **10** and the counter substrate **20** are attached together, the entire boundary BD1 between the first pre-tilt region **12a** and the second pre-tilt region **12b** of the first photo-alignment film **12** and the entire boundary BD2 between the third pre-tilt region **22a** and the fourth pre-tilt region **22b** of the second photo-alignment film **22** are aligned with each other, as seen from the display plane normal direction.

[0095] Note that a step of performing a re-alignment treatment, including a heating treatment, on the liquid crystal layer **30** may be performed after the step of attaching together the active matrix substrate **10** and the counter substrate **20**. By this re-alignment treatment, it is possible to eliminate the orientation disturbance (fluid-flow orientation) occurring when injecting a liquid crystal material.

[0096] Then, the step of attaching the pair of linear polarizers **18** and **28** on the outer side of the active matrix substrate **10** and the counter substrate **20**, and other steps, are performed, thereby obtaining the liquid crystal display device **100** of the present embodiment.

[0097] Note that as already described above, with the liquid crystal display device **100** of the present embodiment, even though there should be formed only two liquid crystal domains in the presence of an applied voltage, when taking into consideration only the alignment regulating force of the first photo-alignment film **12** and the second photo-alignment film **22**, there are actually formed four liquid crystal domains A, B, C and D, thereby realizing a sufficiently high viewing angle characteristic. Particularly, if the screen resolution is 200 ppi or more, it is possible to obtain substantially the same viewing angle characteristic as that for the common 4D-RTN mode, as will be described later in detail.

[0098] Now, referring to FIG. 7 and FIG. 8, the results of an orientation simulation for verifying the orientation of liquid crystal molecules in the presence of an applied voltage will be described, for each of a pixel **1001** of a common 4D-RTN mode and a pixel **1** of the liquid crystal display device **100** of the present embodiment. FIGS. 7(a) to (d) are views relating to the pixel **1001** of the 4D-RTN mode, and FIGS. 8(a) to (d) are views relating to the pixel **1** of the liquid crystal display device **100** of the present embodiment. FIG. 7(a) and FIG. 8(a) are calculation mask diagrams, showing the pre-tilt directions PD1 and PD2 defined by the photo-alignment film on the active matrix substrate side, together with the pre-tilt directions PD3 and PD4 defined by the photo-alignment film on the counter substrate side. FIG. 7(b) and FIG. 8(b) show transmittance simulation results obtained when linear polarizers arranged so that the transmission axes P1 and P2 are generally orthogonal to each other are used as polarizers. FIG. 7(c) and FIG. 8(c) show transmittance simulation results obtained when circular polarizers are used as polarizers. FIG. 7(d) and FIG. 8(d) each show the orientation distribution within a pixel, showing, by using an arrow, the general orientation direction of liquid crystal molecules (which can be said to be the azimuth direction of the director) in each liquid crystal domain. Note that the calculation conditions for the orientation simulation are as shown in Table 1 below.

TABLE 1

Calculation condition		
Dielectric constant of liquid crystal material	Dielectric constant in molecule	3.7
	major axis direction $\epsilon//$	
Refractive index of liquid crystal material	Dielectric constant in molecule	7.8
	minor axis direction $\epsilon\perp$	
	Refractive index in molecule	1.6061
	major axis direction $n//$	
	Refractive index in molecule	1.4862
	minor axis direction $n\perp$	
Cell thickness (thickness of liquid crystal layer)		3.1 μm
Voltage applied to liquid crystal layer		3.75 V

TABLE 1-continued

Calculation condition	
Pixel pitch	28.25 μm $\times$ 84.75 μm (corresponding to screen resolution of 300 ppi)

[0099] As can be seen from FIG. 7(a) and FIG. 8(a), the shape of the pixel electrode, etc., is the substantially same between the pixel **1001** of the 4D-RTN mode and the pixel **1** of the present embodiment.

[0100] Where circular polarizers are used, although a small dark spot is present at the center of the pixel, a high luminance is realized in other areas of the pixel, for the pixel **1001** of the 4D-RTN mode and for the pixel **1** of the present embodiment, as shown in FIG. 7(c) and FIG. 8(c).

[0101] Where linear polarizers are used, there appear swastika-shaped dark lines that is characteristic of the 4D-RTN mode, as shown in FIG. 7(b), with the pixel **1001** of the 4D-RTN mode. On the other hand, with the pixel **1** of the present embodiment, there appear dark lines of substantially the same pattern, as shown in FIG. 8(b), though the dark lines are located slightly different from the pixel **1001** of the 4D-RTN mode. Therefore, it is believed that a 4D structure is formed also with the pixel **1** of the present embodiment.

[0102] As can be seen from FIG. 7(d) and FIG. 8(d), it was confirmed that liquid crystal molecules were oriented generally in four directions for the pixel **1001** of the 4D-RTN mode and for the pixel **1** of the present embodiment.

[0103] Then, referring now to FIG. 9, the reason why four liquid crystal domains are formed in a pixel **1** of the present embodiment will be described.

[0104] As shown in FIG. 9, in the pixel **1** of the present embodiment, the outer perimeter of the pixel electrode **11** includes a first edge portion **11e1** and a second edge portion **11e2**. The first edge portion **11e1** lies near the liquid crystal domain A, and the second edge portion **11e2** lies near the liquid crystal domain C.

[0105] The direction $e1$, which is orthogonal to the first edge portion **11e1** and which extends toward the inside of the pixel electrode **11**, is opposite to the first pre-tilt direction PD1. The direction $e2$, which is orthogonal to the second edge portion **11e2** and which extends toward the inside of the pixel electrode **11**, is opposite to the second pre-tilt direction PD2.

[0106] With the outer perimeter of the pixel electrode **11** including the first edge portion **11e1** and the second edge portion **11e2**, there are formed four liquid crystal domains in the presence of an applied voltage. The reason for this will now be described in greater detail with reference to FIG. 10 and FIG. 11.

[0107] FIG. 10(a) is a plan view showing one pixel **1**, and FIG. 10(a) shows, by solid-line arrows $a1$ and $a2$, the alignment regulating forces from the first photo-alignment film **12** and the second photo-alignment film **22**. FIG. 10(b) is a cross-sectional view taken along line 10B-10B' of FIG. 10(a), showing the orientation of the liquid crystal molecules **31** in the absence of an applied voltage. As can be seen from FIG. 10(b), the liquid crystal molecules **31** are pre-tilted at a predetermined angle (pre-tilt angle) θ in a predetermined direction by virtue of the alignment regulating forces $a1$ and $a2$ from the first photo-alignment film **12** and the second photo-alignment film **22** in the absence of an applied voltage. For example, in the upper half of the pixel **1**, the liquid crystal molecules **31** are tilted leftward with respect to the substrate surface normal direction.

[0108] FIG. 11(a) is a plan view showing one pixel 1, and FIG. 11(a) shows, by broken-line arrows b1, b2, b3 and b4, the alignment regulating forces from an oblique electric field produced in the vicinity of the outer perimeter of the pixel electrode 11, as well as the alignment regulating forces a1 and a2 from the first photo-alignment film 12 and the second photo-alignment film 22. FIG. 11(b) is a cross-sectional view taken along line 11B-11B' of FIG. 11(a), showing the orientation of the liquid crystal molecules 31 in the presence of an applied voltage (without taking into consideration the alignment regulating forces a1 and a2 from the first photo-alignment film 12 and the second photo-alignment film 22). As can be seen from FIG. 11(b), the liquid crystal molecules 31, which have a negative dielectric anisotropy, are oriented so as to be perpendicular to the electric force lines E in the presence of an applied voltage. Therefore, in the vicinity of the outer perimeter of the pixel electrode 11, there are alignment regulating forces urging the liquid crystal molecules 31 to tilt toward the inside of the pixel electrode 11 (the alignment regulating forces b1, b2, b3 and b4 shown in FIG. 11(a)).

[0109] Therefore, in portions of the pixel 1 (herein, an upper left portion and a lower right portion of the pixel 1, i.e., regions R1 and R2 shown in FIG. 11(a)), the directions of the alignment regulating forces from the first photo-alignment film 12 and the second photo-alignment film 22 (directions that coincide with the first pre-tilt direction PD1 and the second pre-tilt direction PD2) are opposite to the directions of the alignment regulating forces from an oblique electric field (directions which are orthogonal to the edge portion of the pixel electrode 11 and which extend toward the inside of the pixel electrode 11). FIG. 11(c) shows, on an enlarged scale, a lower right portion of the pixel 1. In this portion, the alignment regulating force a2 from the first photo-alignment film 12 and the second photo-alignment film 22 and the alignment regulating forces b2 and b3 from an oblique electric field interact with each other, thereby tilting the liquid crystal molecules 31 upward (the direction c). Similarly, in an upper left portion of the pixel 1, the alignment regulating force a1 from the first photo-alignment film 12 and the second photo-alignment film 22 and the alignment regulating forces b1 and b4 from an oblique electric field interact with each other, thereby tilting the liquid crystal molecules 31 downward.

[0110] With the mechanism described above, in the liquid crystal domains A and C in the vicinity of the first edge portion 11e1 and the second edge portion 11e2, the liquid crystal molecules 31 are oriented in the display plane vertical directions (the generally 270° direction and the generally 90° direction) in the presence of an applied voltage. Therefore, four liquid crystal domains A, B, C and D are formed within the pixel 1, of which the azimuth directions of the directors are different from each other.

[0111] Thus, with the liquid crystal display device 100 of the present embodiment, there are actually formed four liquid crystal domains A, B, C and D within each pixel 1 in the presence of an applied voltage, thereby realizing a sufficiently high viewing angle characteristic. Now, the results of an orientation simulation and an optical simulation performed with various screen resolutions (pixel pitches) for verifying the viewing angle characteristic of the liquid crystal display device 100 of the present embodiment will be described.

[0112] The simulation was performed for six screen resolutions as Examples 1 to 6. The simulation was also performed for a liquid crystal display device having pixels 1001 shown in FIG. 2, as Comparative Example 1. The screen

resolutions and the pixel pitches (pixel sizes) of Examples 1 to 6 and Comparative Example 1 are as shown in Table 2 below. The simulation was performed, where the liquid crystal material was a nematic liquid crystal material having a refractive index anisotropy $\Delta n=0.1199$, and the thickness of the liquid crystal layer (the cell thickness) was 3.1 μm . Moreover, the interval between adjacent pixel electrodes was 6 μm , and the pre-tilt angle was 2.4°. A region where the photo-alignment film is exposed redundantly (a redundant exposure region) was formed with a width of 20 μm in the central portion of each pixel, and the pre-tilt angle at the center of the redundant exposure region was set to 0°. The white voltage (highest gray level voltage) was set to 3.9 V based on the measured values for an actual prototype 4.18-inch panel.

TABLE 2

		Screen resolution	Pixel pitch
Example	1	500 ppi	16.93 μm $\times$ 50.8 μm
	2	400 ppi	21.16 μm $\times$ 63.5 μm
	3	300 ppi	28.25 μm $\times$ 84.75 μm
	4	217 ppi	39 μm $\times$ 117 μm
	5	160 ppi	52.91 μm $\times$ 158.75 μm
	6	96 ppi	88.5 μm $\times$ 265.5 μm
Comparative Example 1 (4D-RTN)		96 ppi	88.5 μm $\times$ 265.5 μm

[0113] Referring to FIG. 12 to FIG. 18, simulation results for Examples 1 to 6 and Comparative Example 1 will be described. FIG. 12 corresponds to Example 1, FIG. 13 corresponds to Example 2, and FIG. 14 corresponds to Example 3. FIG. 15 corresponds to Example 4, FIG. 16 corresponds to Example 5, FIG. 17 corresponds to Example 6, and FIG. 18 corresponds to Comparative Example 1.

[0114] In FIG. 12 to FIG. 18, (a) shows a calculation mask diagram. In FIG. 12 to FIG. 18, (b) shows transmittance simulation results obtained when circular polarizers are used as polarizers. In FIG. 12 to FIG. 18, (c) shows transmittance simulation results obtained when linear polarizers arranged so that the transmission axes are generally orthogonal to each other are used as polarizers. In FIG. 12 to FIG. 18, (d) shows the orientation distribution within a pixel, showing, by using an arrow, the general orientation direction of liquid crystal molecules (which can be said to be the azimuth direction of the director) in each liquid crystal domain. In FIG. 12 to FIG. 18, (e) is a graph showing the relationship between the gray level and the luminance (normalized with 1 being the luminance of the white display) for the front direction, for a diagonally right 60° direction (the direction obtained by tilting the viewing angle by 60° rightward), and for a diagonally upper 60° direction (the direction obtained by tilting the viewing angle by 60° upward), indicating how much the

[0115] Y characteristic (the gray level dependence of the luminance) shifts when observed from a diagonal direction than when observed from the front direction. Refer particularly to (e) of FIG. 12 to FIG. 18 in conjunction with the following description.

[0116] As can be seen from FIG. 18, in Comparative Example 1 (common 4D-RTN mode), even though the screen resolution is relatively low (96 ppi, with a pixel pitch of 88.5 μm $\times$ 265.5 μm), there is substantially no luminance difference for substantially every gray level between when observed from the diagonally right 60° direction and when observed

from the diagonally upper 60° direction. This indicates that a desirable viewing angle characteristic is obtained, i.e., there is a small azimuth angle dependence of the characteristic shift (y shift) when observed from a diagonal direction.

[0117] In contrast, as can be seen from FIG. 17, in Example 6 where the screen resolution is the same as Comparative Example 1, the luminance difference between when observed from the diagonally right 60° direction and when observed from the diagonally upper 60° direction is greater than that for Comparative Example 1.

[0118] As can be seen from FIG. 12 to FIG. 17, in Examples 1 to 6, the luminance difference between when observed from the diagonally right 60° direction and when observed from the diagonally upper 60° direction tends to decrease as the screen resolution increases (as the pixel pitch decreases). It can be seen that when the screen definition is 200 ppi or more (Examples 1 to 4), the azimuth angle dependence of the y shift is sufficiently small, thereby realizing a sufficiently high viewing angle characteristic.

[0119] Note that even though Example 6 has a lower screen resolution than Example 5, the luminance difference between when observed from the diagonally right 60° direction and when observed from the diagonally upper 60° direction is smaller than Example 5. It is believed that this is because the calculation is done in Example 6 using such a pattern that the inside of the pixel is partially shaded.

[0120] Then, referring now to FIGS. 19(a), (b) and (c), the reason why a higher viewing angle characteristic is realized as the screen resolution increases. FIGS. 19(a), (b) and (c) are enlarged versions of FIG. 18(d), FIG. 17(d) and FIG. 13(d), showing the orientation distribution within a pixel for Comparative Example 1, Example 6 and Example 2, respectively.

[0121] In Comparative Example 1, as can be seen from FIG. 19(a), four regions in which the liquid crystal molecules are oriented in the lower left direction (a generally 225° direction), the lower right direction (a generally 315° direction), the upper right direction (a generally 45° direction) and the upper left direction (a generally 135° direction) account for a majority of the pixel. Although regions in which the liquid crystal molecules are oriented in the downward direction (a generally 270° direction) and the upward direction (a generally 90° direction) are present in an upper left portion and a lower right portion of the pixel, these regions account for a small proportion of the pixel. Therefore, it can be regarded that the liquid crystal molecules are oriented generally in four directions within a pixel, and the four regions in which the liquid crystal molecules are oriented in the lower left direction, the lower right direction, the upper right direction and the upper left direction are dominant in terms of the optical characteristics.

[0122] In Example 6, in contrast, as can be seen from FIG. 19(b), two regions in which the liquid crystal molecules are oriented in the left direction (a generally 180° direction) and the right direction (a generally 0° direction) account for a majority of the pixel. Although regions in which the liquid crystal molecules are oriented in the downward direction (a generally 270° direction) and the upward (direction (a generally 90° direction) are present in an upper left portion and a lower right portion of the pixel, these regions account for a small proportion of the pixel. Therefore, it can be regarded that the liquid crystal molecules are oriented generally in two directions within a pixel, and the two regions in which the

liquid crystal molecules are oriented in the left direction and the right direction are dominant in terms of the optical characteristics.

[0123] In Example 2, in contrast, as can be seen from FIG. 19(c), regions in which the liquid crystal molecules are oriented in the downward direction and the upward direction account for a higher proportion of the pixel than in Example 6. Therefore, can be regarded that the liquid crystal molecules are oriented generally in four directions within a pixel, and the four regions in which the liquid crystal molecules are oriented in the downward direction, the right direction, the upward direction and the left direction (the four liquid crystal domains A, B, C and D shown in FIG. 4, etc.) are dominant in terms of the optical characteristics.

[0124] As described above, as the screen resolution is higher (i.e., as the pixel pitch is smaller), the difference in area between the four liquid crystal domains decreases, improving the viewing angle characteristic. According to a study by the present inventors, it has been found that if the screen resolution is 200 ppi or more (if the shorter one of the pixel pitch along the display plane horizontal direction and the pixel pitch along the display plane vertical direction is 42 μm or less), the difference between the liquid crystal domain of the largest area and the liquid crystal domain of the smallest area can be made relatively small (specifically, 50% or less), and it is possible to realize a sufficiently high viewing angle characteristic comparable to that of a liquid crystal display device of a common 4D-RTN mode.

[0125] Then, the results of measuring various characteristics of an actual prototype of a liquid crystal display device **100** having a screen resolution of 217 ppi as Example 7 will be described. The results of measuring various characteristics of a prototype of a liquid crystal display device of a 4D-RTN mode having a screen resolution of 217 ppi as Comparative Example 2 and a prototype of a liquid crystal display device of a CPA (Continuous Pinwheel Alignment) mode having a screen resolution of 217 ppi as Comparative Example 3 will also be described. Note that the CPA mode is a type of the VA mode, and is disclosed in Japanese Laid-Open Patent Publication No. 2003-43525 and Japanese Laid-Open Patent Publication No. 2002-202511, for example.

[0126] Table 3 below shows the results of measuring the transmittance and the response speed for Example 7, Comparative Example 2 and Comparative Example 3. As for the response speed, the rising response time Tr when changing the display gray level from 0 gray level to 32 gray level at 25° C., and the falling response time Td when changing it from 32 gray level to 0 gray level are shown. Table 3 also shows the temperature of the heating treatment in the re-alignment treatment step and the pre-tilt angle (average pre-tilt angle) for Example 7 and Comparative Example 2. Note that two liquid crystal display devices **100** of different heating treatment temperatures were prototyped as Example 7.

TABLE 3

	Example 7		Comparative Example 2 (4D-RTN)	Comparative Example 3 (CPA)
Transmittance	6.6%		6.6%	6.4%
Heating treatment (re-alignment)	110° C.	130° C.	130° C.	—

TABLE 3-continued

		Example 7	Comparative Example 2 (4D-RTN)	Comparative Example 3 (CPA)
treatment) temperature				
Pre-tilt angle		2.0°	1.4-1.5°	0.9°
Res- ponse speed (25° C.)	Rising response time T_r (0→32 gray level)	51.9 msec	59.4 msec	116.6 msec
	Falling response time T_d (32→0 gray level)	9.0 msec	8.6 msec	10.3 msec

[0127] As can be seen from Table 3, the rising response time T_r of Comparative Example 2 (4D-RTN mode) is longer (twice or more) than Comparative Example 3 (CPA mode). It is believed that this is because the proportion of the pixel accounted for by the undesirable tilt region increases, thereby reducing the average pre-tilt angle, as already described above.

[0128] In contrast, Example 7 realizes substantially the same rising response time as that of Comparative Example 3. It is believed that this is because the lowering of the average pre-tilt angle is suppressed as already described above.

[0129] Example 7 realizes a higher transmittance than that of Comparative Example 3. It is often the case with the CPA mode that an alignment regulating means (projections made of a dielectric material or openings made in the counter electrode) for fixing the center of the axially symmetric orientation to thereby stabilize the orientation is provided on the counter substrate side, and this alignment regulating means causes the lowering of the transmittance. In contrast, the liquid crystal display device 100 of the present embodiment does not require such an alignment regulating means, and it is therefore possible to realize a high transmittance.

[0130] FIGS. 20(a) and (b) show, for Example 7 and Comparative Example 2, the relationship between the gray level and the luminance (normalized luminance) when observed from the front direction, that when observed from the diagonally left/right 60° direction, and that when observed from the diagonally upper/lower 60° direction. As can be seen from FIGS. 20(a) and (b), the azimuth angle dependence of the y shift was small and a sufficiently high viewing angle characteristic was realized in Example 7, as in Comparative Example 2. Note that although not shown in the figures, a similarly high viewing angle characteristic to that of Comparative Example 2 was realized also in Comparative Example 3.

[0131] In Table 3 above, as can be seen from a comparison between two liquid crystal display devices 100 prototyped as Example 7, a larger average pre-tilt angle can be obtained when the temperature of the heating treatment in the re-alignment treatment step is lower. Specifically, the heating treatment is preferably performed at 110° C. or less. Note however that the effect of the re-alignment treatment may not be sufficient with a temperature less than $T_{NI}+10^\circ$ C. (where T_{NI} is the nematic phase-isotropic phase transition temperature of the liquid crystal material), and it is therefore preferred that the heating treatment is $T_{NI}+10^\circ$ C. or more.

[0132] Note that the reason why a higher average pre-tilt angle can be obtained when the temperature of the heating treatment is lower may be as follows.

[0133] It is believed that a pre-tilt angle is realized (a pre-tilt direction is defined) by a photo-alignment film because when a photo-alignment film (typically made of a polyimide-based material) is irradiated with ultraviolet light, the side chain turns toward where the ultraviolet light is coming in by virtue of a photoreaction of the photofunctional group. However, since this reaction is reversible with respect to heat, the pre-tilt angle returns to the original (before the photo-alignment treatment) pre-tilt angle (0°, or 90° with respect to the substrate plane) if the heating treatment in the re-alignment treatment step is performed at a high temperature over a long period of time. Therefore, it is believed that the heating treatment is preferably performed at a lower temperature.

[0134] Now, referring to FIGS. 21(a) and (b), the basic structure of the CPA mode mentioned in Comparative Example 3 will be described. FIGS. 21(a) and (b) are a cross-sectional view and a plan view, respectively, schematically showing one pixel of a liquid crystal display device 900 of the CPA mode.

[0135] The liquid crystal display device 900 includes an active matrix substrate 910 and a counter substrate 920 arranged so as to oppose each other, and a liquid crystal layer 930 of a vertical alignment type provided therebetween.

[0136] The active matrix substrate 910 includes a pixel electrode 911 provided in each pixel, and a vertical alignment film 912 provided between the pixel electrode 911 and the liquid crystal layer 930. The pixel electrode 911 and the vertical alignment film 912 are supported on a transparent substrate 910a.

[0137] The counter substrate 920 includes a counter electrode 921 opposing the pixel electrode 911, and a vertical alignment film 922 provided between the counter electrode 921 and the liquid crystal layer 930. The counter electrode 921 and the vertical alignment film 922 are supported on a transparent substrate 920a. The counter electrode 921 has an opening 921a formed in a region opposing generally the center of the pixel electrode 911.

[0138] When a voltage is applied across the liquid crystal layer 930, liquid crystal molecules 931 are oriented in an axially symmetric orientation, as shown in FIGS. 21(a) and (b), by the alignment regulating force of an oblique electric field produced in the vicinity of the outer perimeter of the pixel electrode 911 and the alignment regulating force of an oblique electric field produced in the vicinity of the opening 921a of the counter electrode 921.

[0139] The opening 921a of the counter electrode 921 functions to fix the center of the axially symmetric orientation and to stabilize the orientation. As an alignment regulating means having such a function, a projection (referred to also as a rivet) made of a dielectric material may also be used instead of the opening 921a of the counter electrode 921. Note however that since the liquid crystal molecules 931 in the vicinity of the alignment regulating means tend not to tilt in the presence of an applied voltage, thereby lowering the luminance. FIG. 21(c) shows the transmittance simulation results when a white voltage is applied across the liquid crystal layer 930 of the liquid crystal display device 900 (including circular polarizers as polarizers). As can be seen from FIG. 21(c), a region corresponding to the opening 921a of the counter electrode 921 appears dark, lowering the luminance.

[0140] In order to suppress such lowering of the luminance, one may consider reducing the size of the alignment regulating means itself (typically about 10 μm in diameter for the opening 921a formed in the counter electrode 921). However, when the size of the alignment regulating means is reduced, it may become impossible to sufficiently stabilize the orientation due to an insufficient alignment regulating force. Moreover, in order to form a minute alignment regulating means, it is necessary to introduce a new piece of equipment such as a high-resolution stepper.

[0141] Therefore, since the size of the alignment regulating means cannot be reduced below a certain level, if the pixel pitch decreases due to an increase in the definition, it will increase the proportion of the entire pixel accounted for by the alignment regulating means for fixing the center. While the CPA mode at present is often employed in medium- to small-size liquid crystal display devices, the luminance will be low, with liquid crystal display devices of the CPA mode, if the pixel pitch decreases due to an increase in the definition, for the reason described above.

[0142] In contrast, with the liquid crystal display device 100 of the present embodiment, particularly when circular polarizers are used as polarizers, there is little loss of the luminance and it is possible to realize a high transmittance, as can be seen from FIG. 8(c), etc.

[0143] As already described above, it is believed that the response speed of the liquid crystal display device 100 of the present embodiment improves because the area of the undesirable tilt region NGR is smaller than a liquid crystal display device of the 4D-RTN mode. The results of a test by the present inventors checking whether or not undesirable tilt regions NGR are actually formed due to the optical diffraction phenomenon, and the widths of the undesirable pre-tilt regions NGR if they are actually formed will be described below.

[0144] First as shown in FIG. 22(a), a substrate 810 with a photo-alignment film 812 formed thereon is prepared, and the photo-alignment film 812 of the substrate 810 is irradiated with ultraviolet light from a direction indicated by an arrow.

[0145] Next, as shown in FIG. 22(b), irradiation with ultraviolet light was done from a direction indicated by an arrow (the opposite direction from the direction shown in FIG. 22(a)) with some regions of the photo-alignment film 812 being shaded by a photomask including light-blocking portions 815 arranged in a stripe pattern.

[0146] Through two exposures as described above, a region (first region) 812a, which has been irradiated only once with ultraviolet light, and a region (second region) 812b, which has been irradiated twice with ultraviolet light, are formed on the photo-alignment film 812, as shown in FIG. 22(c). The first region 812a became, through irradiation with ultraviolet light in the first exposure step, a region where a large pre-tilt angle (specifically, 2.5°) can be realized. In contrast, the second region 812b was more influenced by irradiation with ultraviolet light in the second exposure step, of the two exposure steps in which irradiation with ultraviolet light is done from opposite directions, and the second region 812b became a region where a small pre-tilt angle (specifically, -0.5°) can be realized.

[0147] Two substrates 810 with two different regions 812a and 812b formed on the photo-alignment film 812 were prepared, and they were attached together while being misaligned with each other by a predetermined angle (herein, 2°), as shown in FIG. 23. As for cross sections (taken along broken

lines shown in the figure) of the panel obtained through the attachment process, there are a cross section (referred to as an “enhanced region”) including regions where the first regions 812a oppose each other and regions where the second regions 812b oppose each other, a cross section (referred to as an “offset region”) only including regions where the first region 812a and the second region 812b oppose each other, and a cross section (referred to as an “intermediate region”) where those regions coexist.

[0148] FIG. 24 shows the position profile of the pre-tilt angle along the Y direction (the left-right direction in FIG. 23) for each of the enhanced region, the intermediate region and the offset region. Now, in order to check the influence of the diffraction of light, the pre-tilt angle in the enhanced region will be discussed. FIG. 24 also shows positions of the light-blocking portions and the light-transmitting portions of the photomask. Note that the pre-tilt angle is 2.55° when the entire surface is exposed only once without using a photomask.

[0149] As can be seen from FIG. 24, the pre-tilt angle changes from 2.5° to -0.5° in each region which has a width of about 20 to 40 μm and which is centered about the boundary between the light-blocking portion and the light-transmitting portion of the photomask. Thus, there actually are regions where the pre-tilt angle lowers due to the optical diffraction phenomenon. Therefore, as with the liquid crystal display device 100 of the present embodiment, the entire boundary BD1 between the first pre-tilt region 12a and the second pre-tilt region 12b of the first photo-alignment film 12 and the entire boundary BD2 between the third pre-tilt region 22a and the fourth pre-tilt region 22b of the second photo-alignment film 22 can be aligned with each other to reduce the area of the undesirable tilt region NGR, thereby suppressing the lowering of the average pre-tilt angle of the entire pixel 1.

[0150] Then, the results of measuring the distribution of the pre-tilt angle within a pixel 1, for two liquid crystal display devices 100 prototyped as Example 7 (screen resolution: 217 ppi, pixel pitch: 39 $\mu\text{m} \times 117 \mu\text{m}$), will be described. FIGS. 25(a) and (b) are graphs showing the relationship between the position in the pixel 1 and the pre-tilt angle, for a case where the temperature of the heating treatment in the re-alignment treatment step is 110°C . and for a case where it is 130°C ., respectively (the time is 40 min for both cases). Note that the vertical axis of the graphs of FIGS. 25(a) and (b) represents the tilt angle with respect to the substrate plane. The measurement of the pre-tilt angle was done along the direction Y shown in FIG. 26. FIG. 26 is an optical microscope image corresponding to one pixel 1.

[0151] It can be seen from FIGS. 25(a) and (b) that a region which has a width of about 20 μm and which is centered about the boundary between pre-tilt regions has become a region where a sufficient pre-tilt angle cannot be realized (undesirable tilt region), but a sufficiently large pre-tilt angle can be realized in other regions.

[0152] It can be seen from a comparison between FIG. 25(a) and FIG. 25(b) that a larger pre-tilt angle can be realized when the temperature of the heating treatment in the re-alignment treatment step is lower.

[0153] Note that the description of the present embodiment is directed to a case where the first photo-alignment film 12 and the second photo-alignment film 22 are divided into two regions in the up-down direction in each pixel 1, and the first pre-tilt direction PD1, the second pre-tilt direction PD2, the third pre-tilt direction PD3 and the fourth pre-tilt direction

PD4 are generally parallel to the left-right direction of the display plane, as shown in FIGS. 5(a) and (b). However, the form of alignment division is not limited to those illustrated above. For example, where each pixel has an horizontally-elongated shape (the length of the pixel along the display plane left-right direction is greater than the length of the pixel along the display plane up-down direction), the first photo-alignment film 12 and the second photo-alignment film 22 may be divided into two regions in the left-right direction in each pixel 1 so that the first pre-tilt direction PD1, the second pre-tilt direction PD2, the third pre-tilt direction PD3 and the fourth pre-tilt direction PD4 are generally parallel to the up-down direction of the display plane.

[0154] Although the present embodiment is directed to a case where one color display pixel is formed by three pixels and the aspect ratio of one pixel is 3:1, the number of pixels to be included in one color display pixel and the aspect ratio of one pixel are not limited to those illustrated herein.

INDUSTRIAL APPLICABILITY

[0155] An embodiment of the present invention is directed to a liquid crystal display device of a VA mode which is suitable for higher-definition applications, and in which the pre-tilt direction of liquid crystal molecules is defined by a photo-alignment film.

REFERENCE SIGNS LIST

- [0156] 1 Pixel
- [0157] 10 Active matrix substrate
- [0158] 11 Pixel electrode
- [0159] 11e1 First edge portion
- [0160] 11e2 Second edge portion
- [0161] 12 First photo-alignment film
- [0162] 12a First pre-tilt region
- [0163] 12b Second pre-tilt region
- [0164] 18, 28 Polarizer (linear polarizer)
- [0165] 20 Counter substrate
- [0166] 21 Counter electrode
- [0167] 22 Second photo-alignment film
- [0168] 22a Third pre-tilt region
- [0169] 22b Fourth pre-tilt region
- [0170] 30 Liquid crystal layer
- [0171] 31 Liquid crystal molecules
- [0172] 100 Liquid crystal display device
- [0173] e1 Direction which is orthogonal to first edge portion and which extends toward inside of pixel electrode
- [0174] e2 Direction which is orthogonal to second edge portion and which extends toward inside of pixel electrode
- [0175] A, B, C, D Liquid crystal domain
- [0176] BD1 Boundary between first pre-tilt region and second pre-tilt region
- [0177] BD2 Boundary between third pre-tilt region and fourth pre-tilt region
- [0178] NGR, NGR1, NGR2 Undesirable tilt region
- [0179] PD1 First pre-tilt direction
- [0180] PD2 Second pre-tilt direction
- [0181] PD3 Third pre-tilt direction
- [0182] PD4 Fourth pre-tilt direction
- [0183] P1, P2 Transmission axis of linear polarizer

1. A liquid crystal display device including a plurality of pixels arranged in a matrix pattern, the liquid crystal display device comprising:

a first substrate and a second substrate arranged so as to oppose each other; and

a liquid crystal layer of a vertical alignment type provided between the first substrate and the second substrate, wherein:

the first substrate includes a pixel electrode provided in each of the plurality of pixels, and a first photo-alignment film provided between the pixel electrode and the liquid crystal layer;

the second substrate includes a counter electrode opposing the pixel electrode, and a second photo-alignment film provided between the counter electrode and the liquid crystal layer;

the first photo-alignment film has, in each of the plurality of pixels, a first pre-tilt region defining a first pre-tilt direction, and a second pre-tilt region defining a second pre-tilt direction, which is anti-parallel to the first pre-tilt direction;

the second photo-alignment film has, in each of the plurality of pixels, a third pre-tilt region defining a third pre-tilt direction, and a fourth pre-tilt region defining a fourth pre-tilt direction, which is anti-parallel to the third pre-tilt direction;

as seen from a display plane normal direction, an entire boundary between the first pre-tilt region and the second pre-tilt region of the first photo-alignment film and an entire boundary between the third pre-tilt region and the fourth pre-tilt region of the second photo-alignment film are aligned with each other;

when a voltage is applied between the pixel electrode and the counter electrode, four liquid crystal domains are formed in the liquid crystal layer in each of the plurality of pixels; and

azimuth directions of four directors representing orientation directions of liquid crystal molecules included in the four liquid crystal domains, respectively, are different from each other.

2. The liquid crystal display device according to claim 1, wherein:

as seen from the display plane normal direction, the first pre-tilt region of the first photo-alignment film and the third pre-tilt region of the second photo-alignment film are aligned with each other and the second pre-tilt region of the first photo-alignment film and the fourth pre-tilt region of the second photo-alignment film are aligned with each other; and

the third pre-tilt direction is anti-parallel to the first pre-tilt direction, and the fourth pre-tilt direction is anti-parallel to the second pre-tilt direction.

3. The liquid crystal display device according to claim 1, wherein:

an outer perimeter of the pixel electrode includes a first edge portion and a second edge portion;

a direction which is orthogonal to the first edge portion and which extends toward inside of the pixel electrode is opposite to the first pre-tilt direction; and

a direction which is orthogonal to the second edge portion and which extends toward inside of the pixel electrode is opposite to the second pre-tilt direction.

4. (canceled)

5. The liquid crystal display device according to claim 1, further comprising:

a pair of linear polarizers which are arranged so as to oppose each other with the liquid crystal layer inter-

posed therebetween and so that transmission axes thereof are generally orthogonal to each other, wherein the transmission axes of the pair of linear polarizers form an angle of generally 45° with respect to the first pre-tilt direction.

6. The liquid crystal display device according to claim 1, further comprising a pair of circular polarizers opposing each other with the liquid crystal layer interposed therebetween.

7. The liquid crystal display device according to claim 1, wherein the liquid crystal layer includes liquid crystal molecules having a negative dielectric anisotropy.

8. The liquid crystal display device according to claim 1, wherein a shorter one of a pixel pitch along a display plane horizontal direction and a pixel pitch along a display plane vertical direction is $42\ \mu\text{m}$ or less.

9. The liquid crystal display device according to claim 1, wherein a screen resolution is 200 ppi or more.

10. A method for manufacturing a liquid crystal display device including a plurality of pixels arranged in a matrix pattern, the liquid crystal display device comprising: a first substrate and a second substrate arranged so as to oppose each other; and a liquid crystal layer of a vertical alignment type provided between the first substrate and the second substrate,

wherein the first substrate includes a pixel electrode provided in each of the plurality of pixels, and a first photo-alignment film provided between the pixel electrode and the liquid crystal layer; the second substrate includes a counter electrode opposing the pixel electrode, and a second photo-alignment film provided between the counter electrode and the liquid crystal layer; when a voltage is applied between the pixel electrode and the counter electrode, four liquid crystal domains are formed in the liquid crystal layer in each of the plurality of pixels; and azimuth directions of four directors representing orientation directions of liquid crystal mol-

ecules included in the four liquid crystal domains, respectively, are different from each other, the method comprising:

a step (A) of forming, through a photo-alignment treatment, in each of regions of the first photo-alignment film corresponding to the plurality of pixels, a first pre-tilt region defining a first pre-tilt direction and a second pre-tilt region defining a second pre-tilt direction, which is anti-parallel to the first pre-tilt direction;

a step (B) of forming, through a photo-alignment treatment, in each of regions of the second photo-alignment film corresponding to the plurality of pixels, a third pre-tilt region defining a third pre-tilt direction and a fourth pre-tilt region defining a fourth pre-tilt direction, which is anti-parallel to the third pre-tilt direction; and

a step (C) of attaching the first substrate and the second substrate with each other, after the step (A) and the step (B),

wherein the step (A) and the step (B) are carried out so that when the first substrate and the second substrate are attached together in the step (C), an entire boundary between the first pre-tilt region and the second pre-tilt region of the first photo-alignment film and an entire boundary between the third pre-tilt region and the fourth pre-tilt region of the second photo-alignment film are aligned with each other as seen from a display plane normal direction.

11. The method for manufacturing a liquid crystal display device according to claim 10, further comprising:

a step (D) of subjecting the liquid crystal layer to a re-alignment treatment including a heating treatment, after the step (C),

wherein the heating treatment is performed at 110°C . or less.

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专利名称(译)	液晶显示装置及其制造方法		
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摘要(译)

液晶显示装置 (100) 包括垂直取向型的液晶层 (30) , 第一光取向膜 (12) , 和第二光取向膜 (22) 。第一光取向膜包括第一预倾斜区域 (12) 和第二预倾斜区域 (12 b) 定义彼此反平行的预倾斜方向 (PD 1 , PD 2) 。第二光取向膜包括第三预倾斜区域 (22) 和第四预倾斜区域 (22 b) 定义彼此反平行的预倾斜方向 (PD 3 , PD) 。第一预倾斜区域和第二预倾斜区域之间的整个边界 (BD 1) 和第三预倾斜区域之间的整个边界 (BD 2) 从显示平面法线方向看, 第四预倾斜区域彼此对齐。

