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Kubo et al.

(54) **LIQUID CRYSTAL DISPLAY DEVICE**

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(51) **Int. Cl.**^{7} **G02F 1/1333**

(52) **U.S. Cl.** **349/138**; 349/139

(57) **ABSTRACT**

The present invention provides a liquid crystal display device having a high display quality. The liquid crystal display device displays an image by applying a voltage by a first electrode and a second electrode across a liquid crystal layer which takes a vertical alignment in the absence of an applied voltage. The first electrode includes a lower conductive layer, a dielectric layer covering at least a portion of the lower conductive layer, and an upper conductive layer provided on one side of the dielectric layer which is closer to the liquid crystal layer. The upper conductive layer includes a first opening, and the lower conductive layer is provided so as to oppose at least a portion of the first opening via the dielectric layer.

FIG. 1A

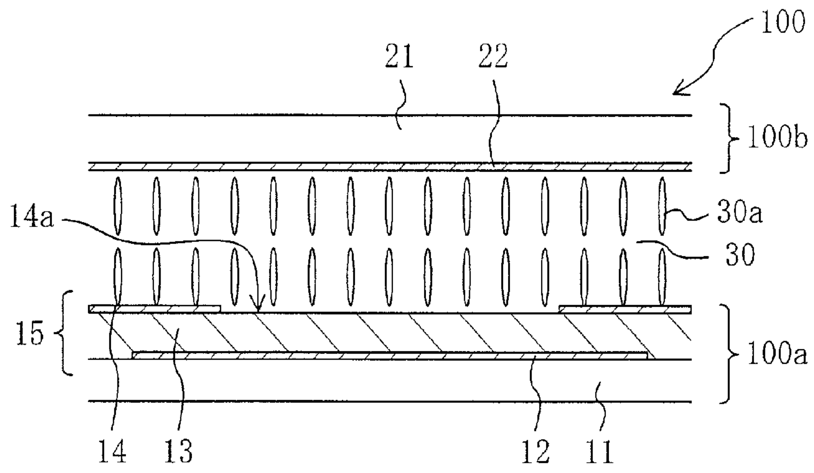


FIG. 1B

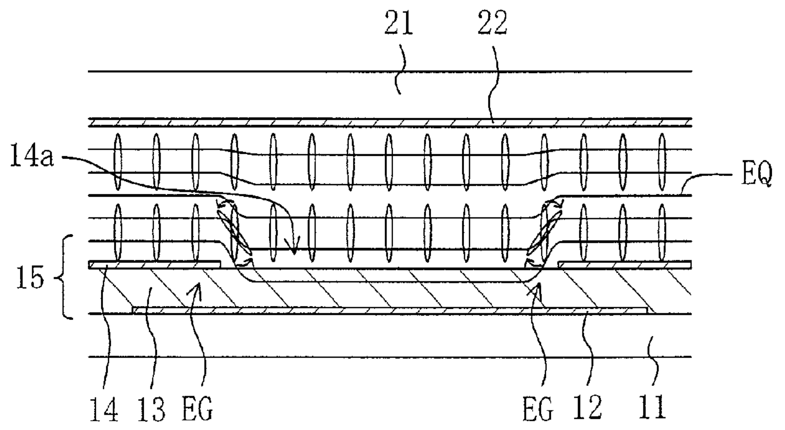


FIG. 1C

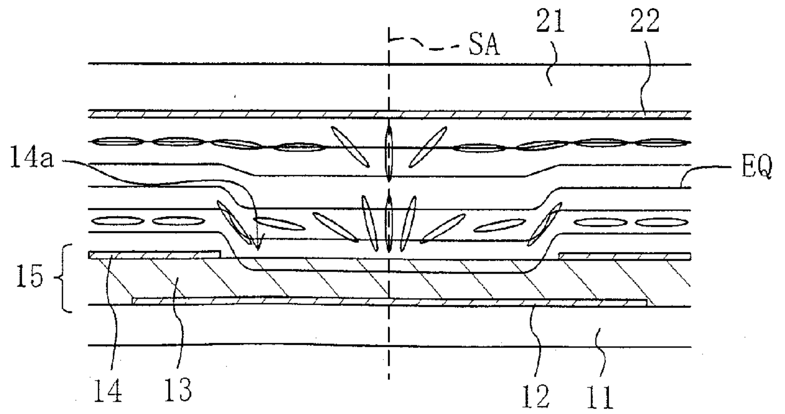


FIG. 2A

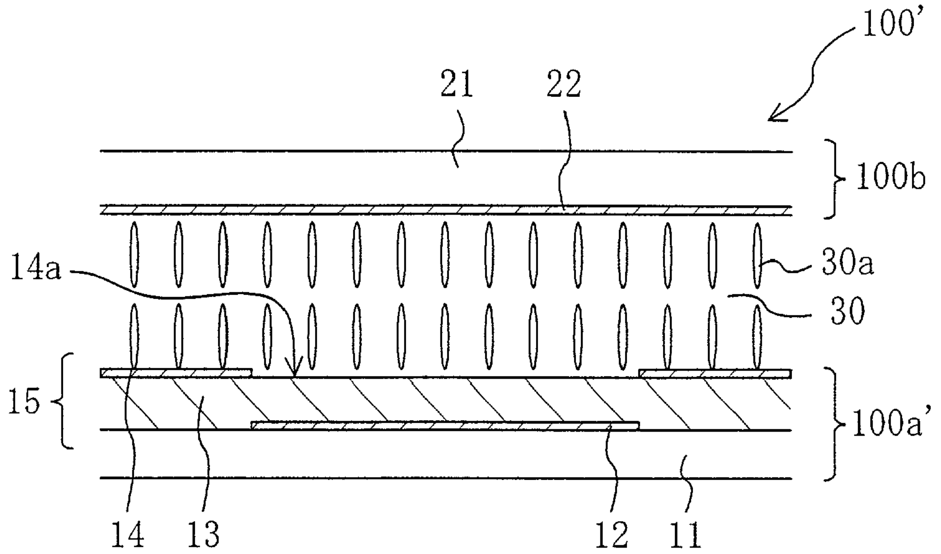

100'
21
22
100b
30a
14a
30
15
100a'
14
13
12
11

FIG. 2B

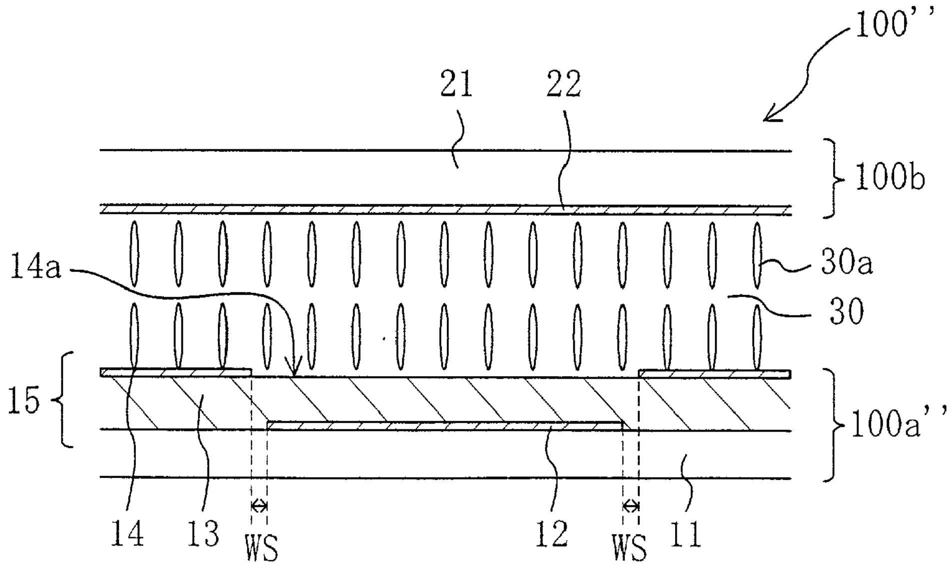

100''
21
22
100b
30a
14a
30
15
100a''
14
13
WS
12
WS
11

FIG. 3A

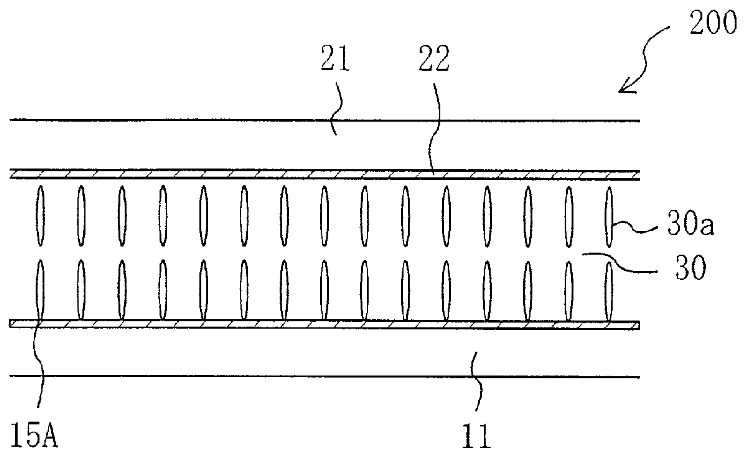


FIG. 3B

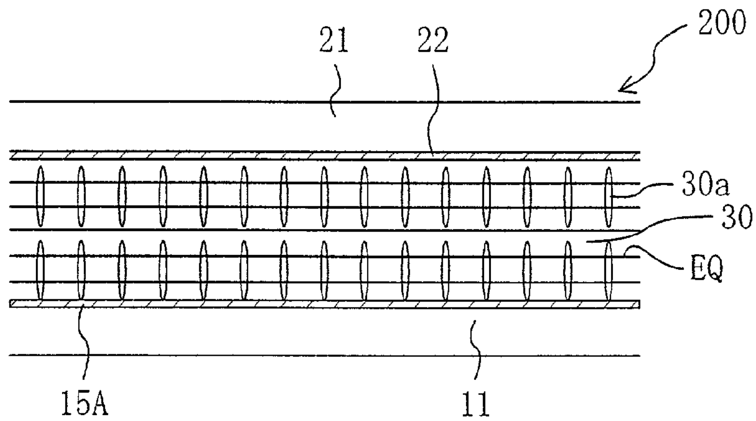
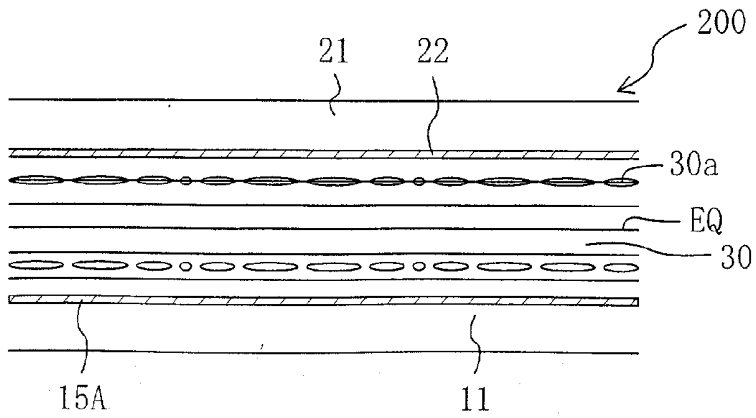


FIG. 3C



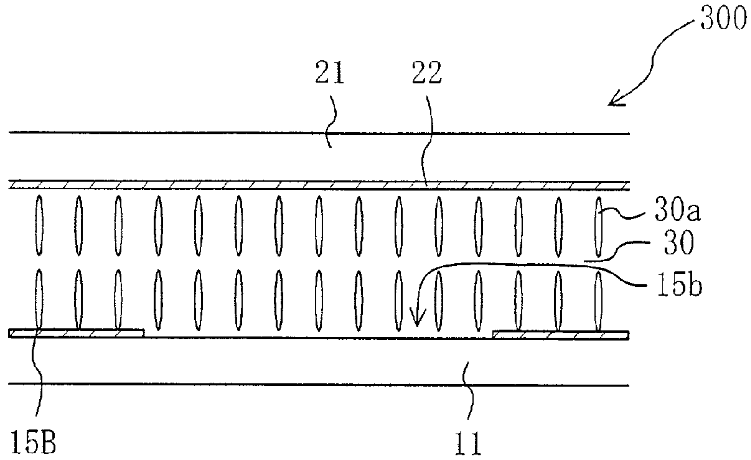


FIG. 4A

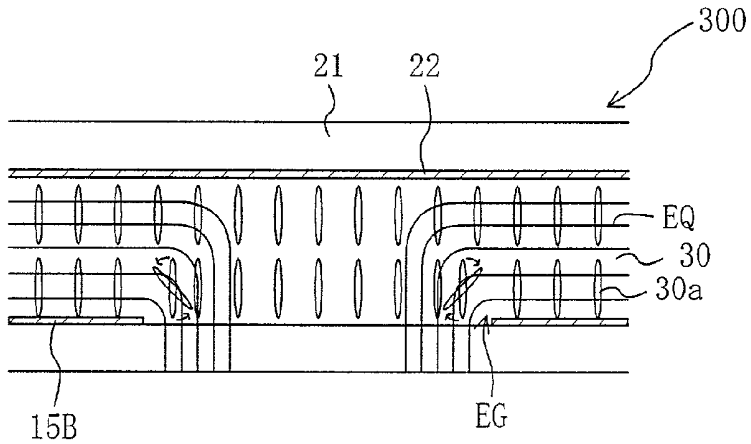


FIG. 4B

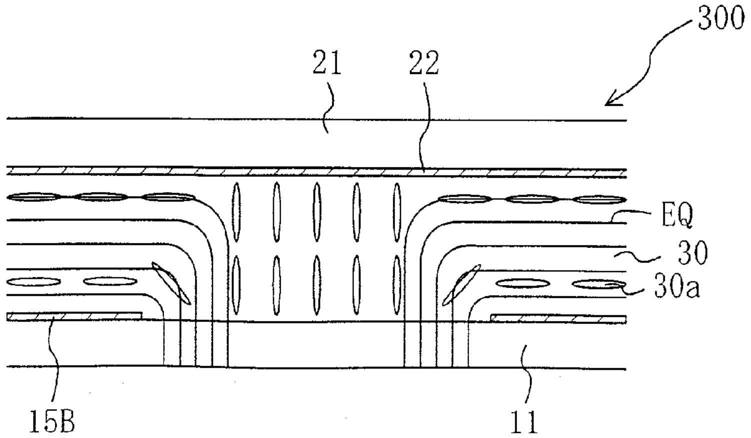


FIG. 4C

FIG. 5A

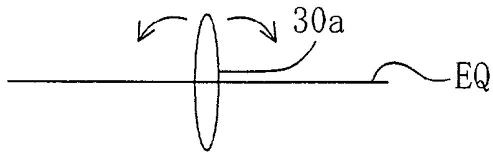


FIG. 5B

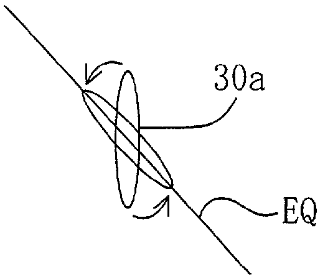


FIG. 5C

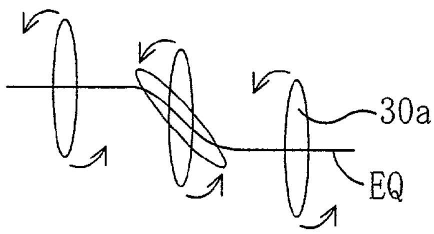


FIG. 5D

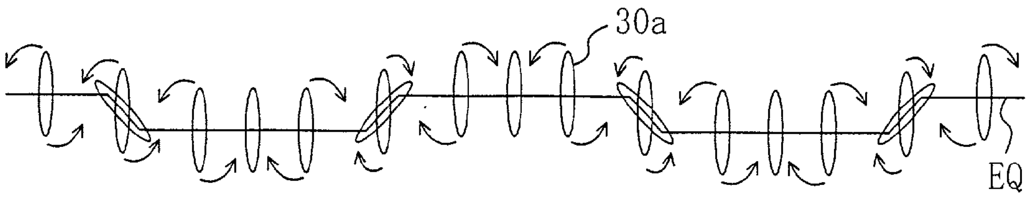


FIG. 6A

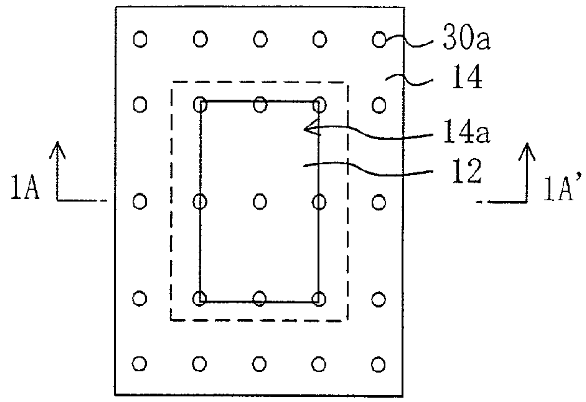


FIG. 6B

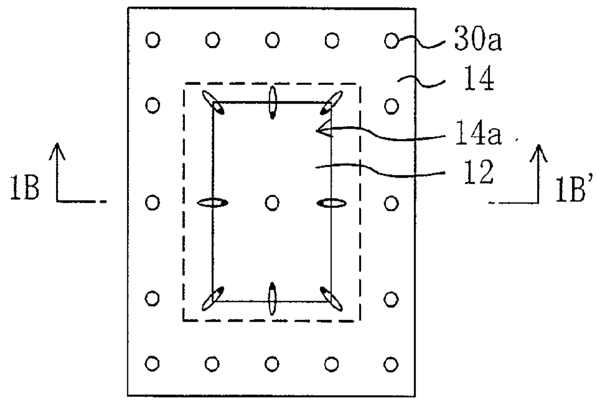


FIG. 6C

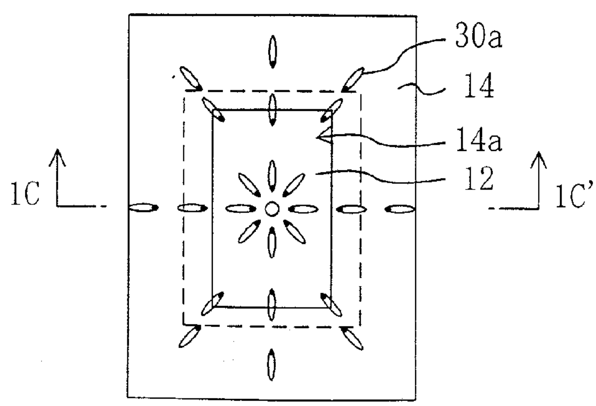


FIG. 7A

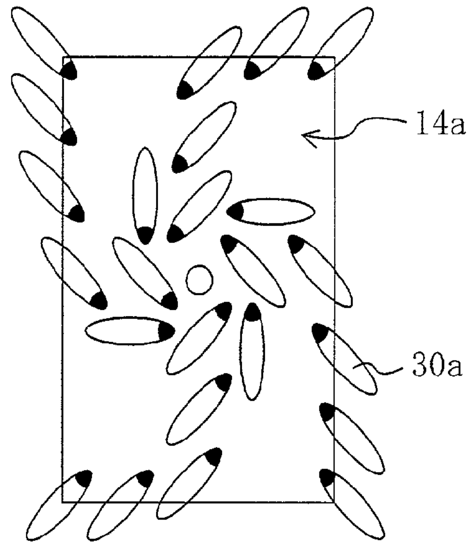


FIG. 7B

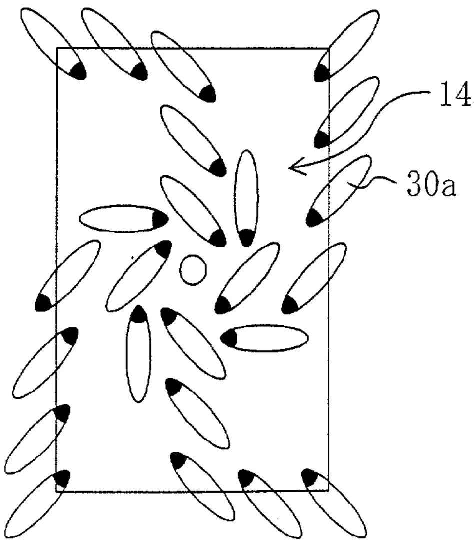


FIG. 8A

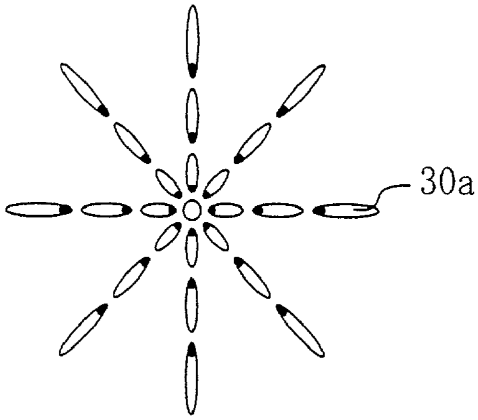


FIG. 8B

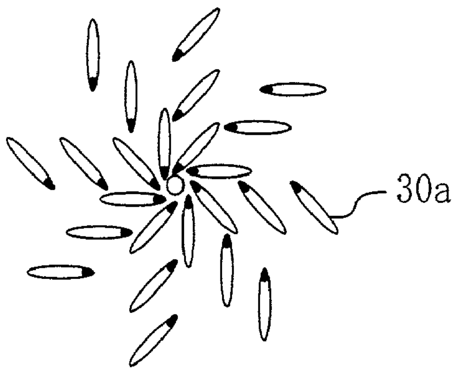


FIG. 8C

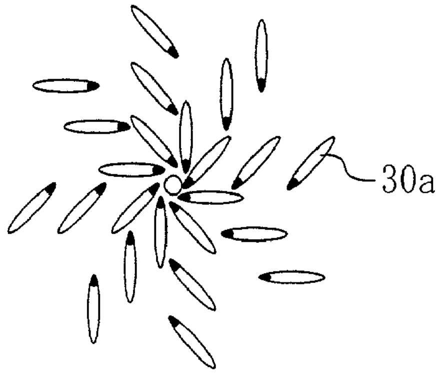


FIG. 9A

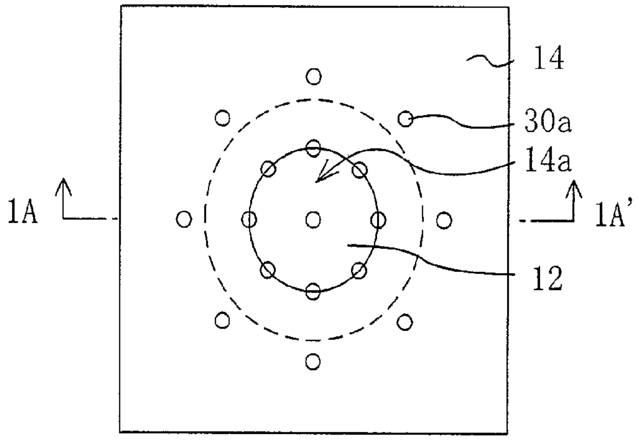


FIG. 9B

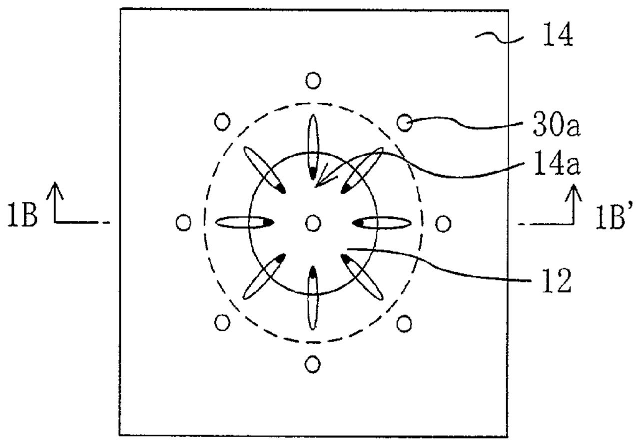


FIG. 9C

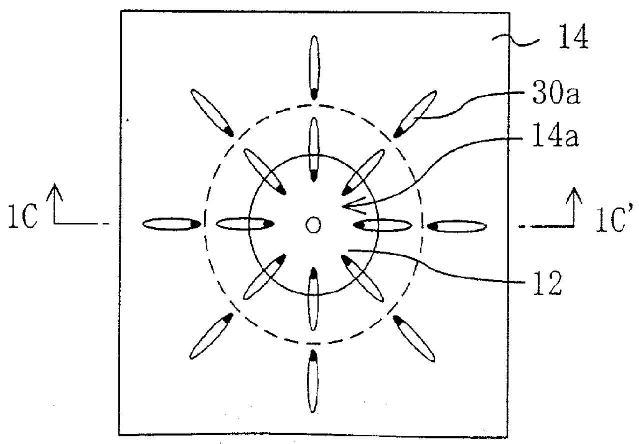


FIG. 10A

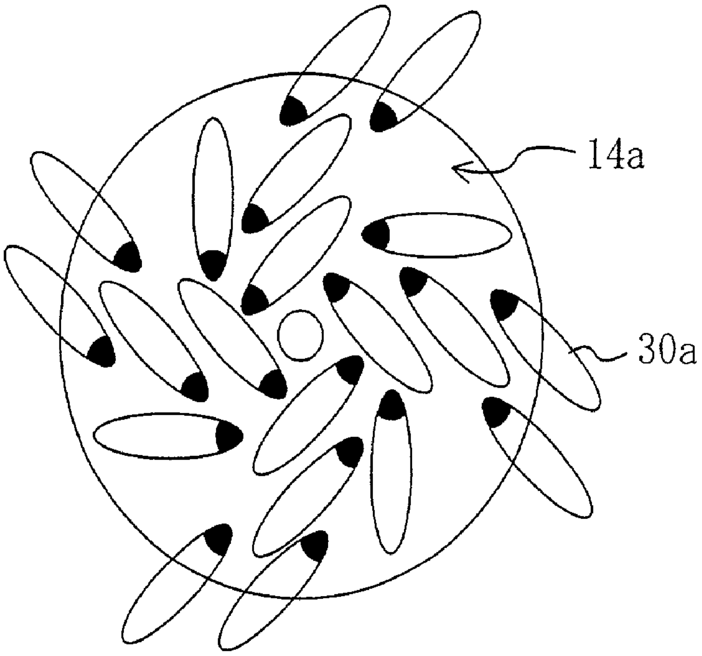


FIG. 10B

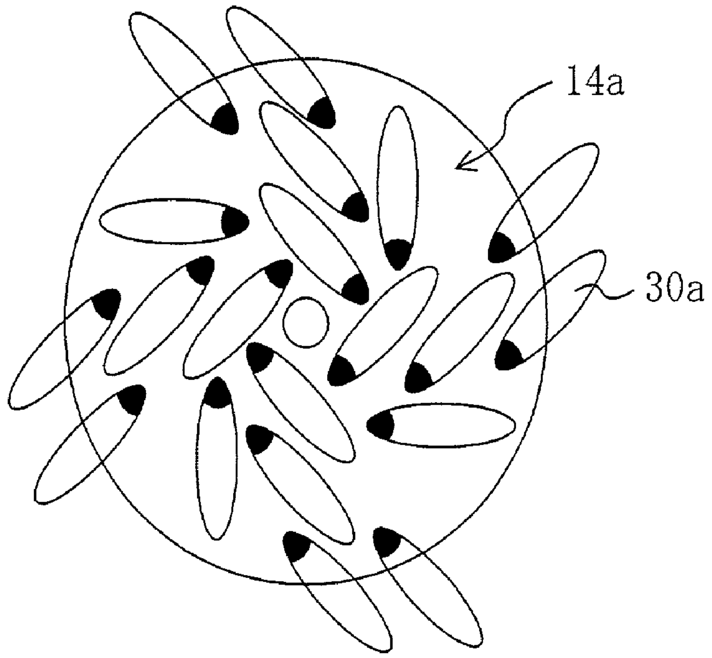


FIG. 11A

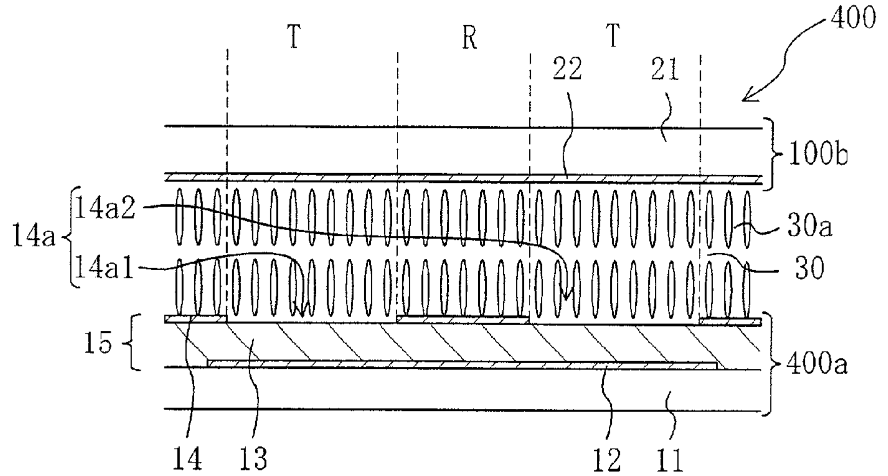


FIG. 11B

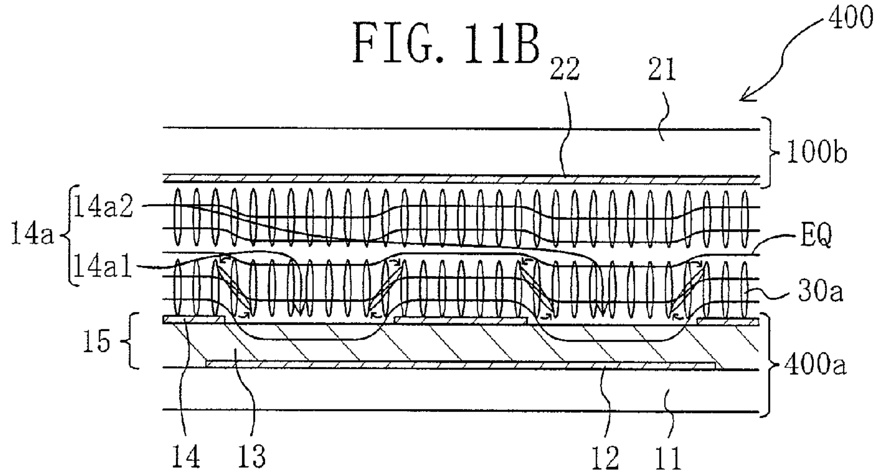


FIG. 11C

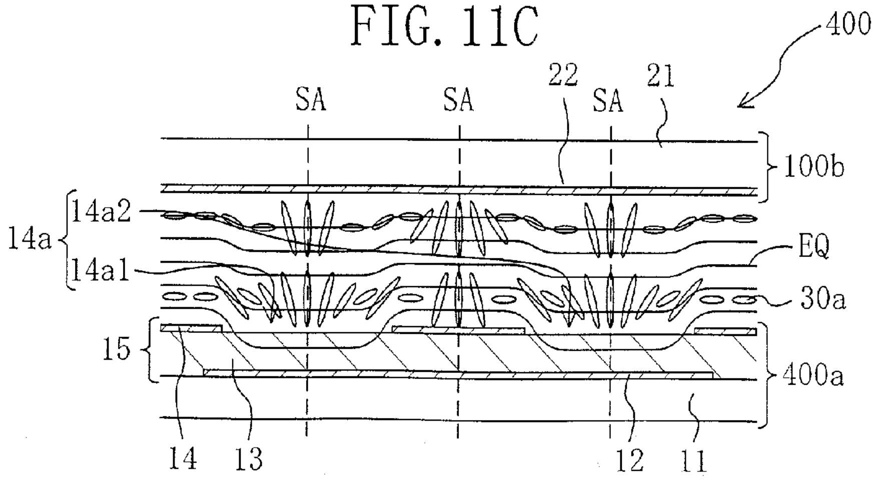


FIG. 12A

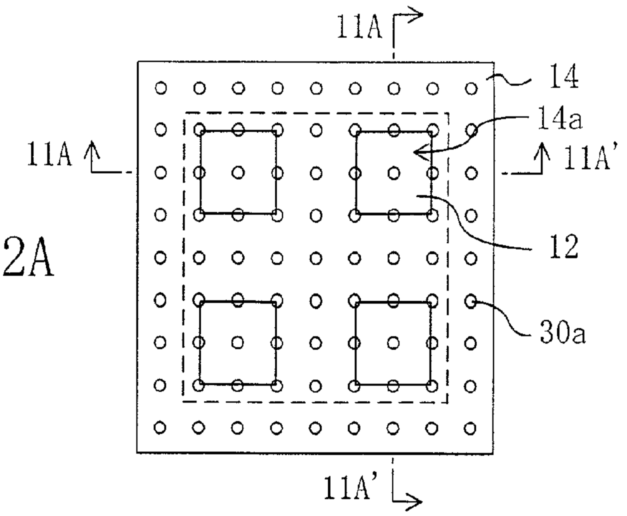


FIG. 12B

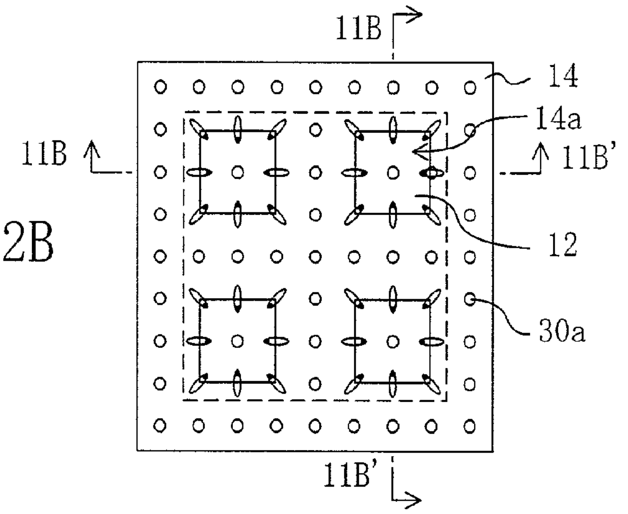
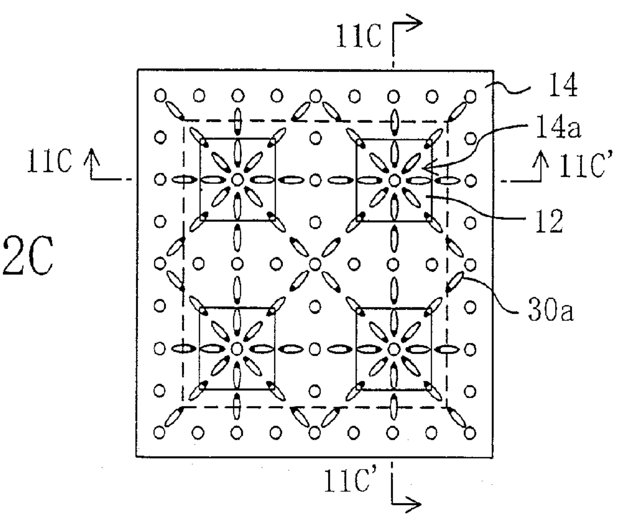


FIG. 12C



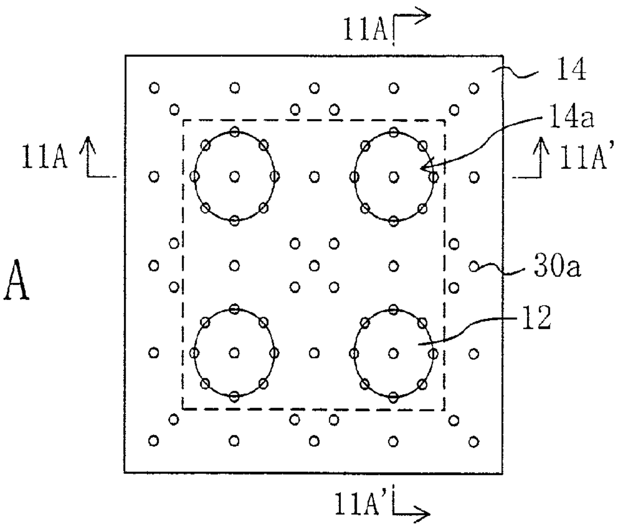


FIG. 13A

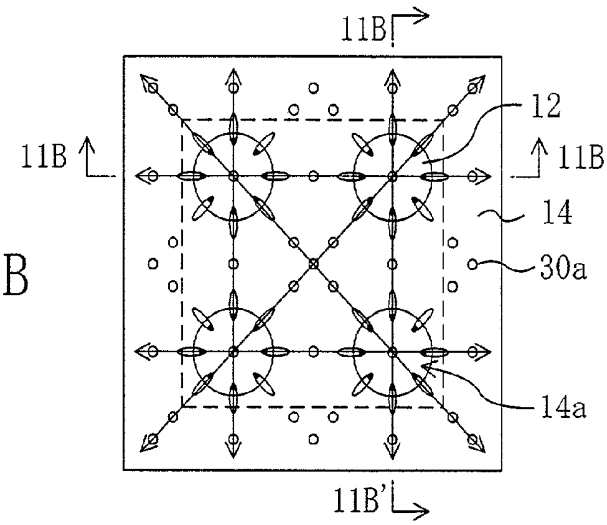


FIG. 13B

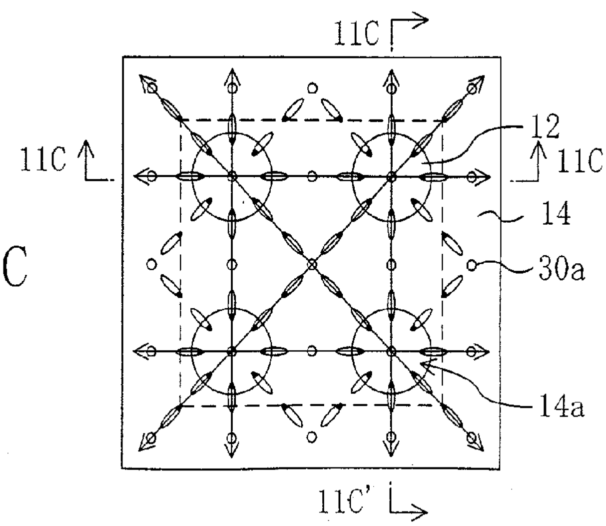


FIG. 13C

FIG. 14

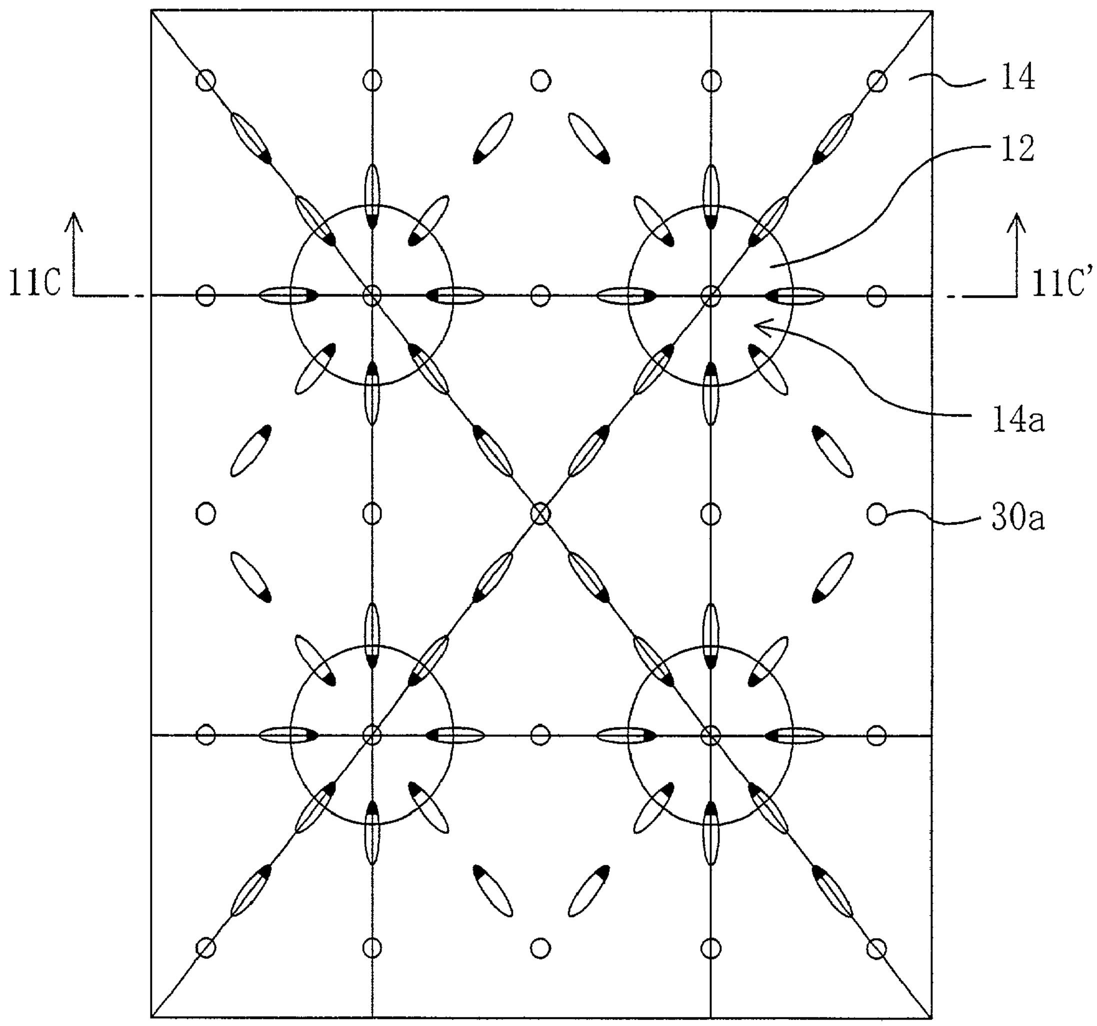


FIG. 15A

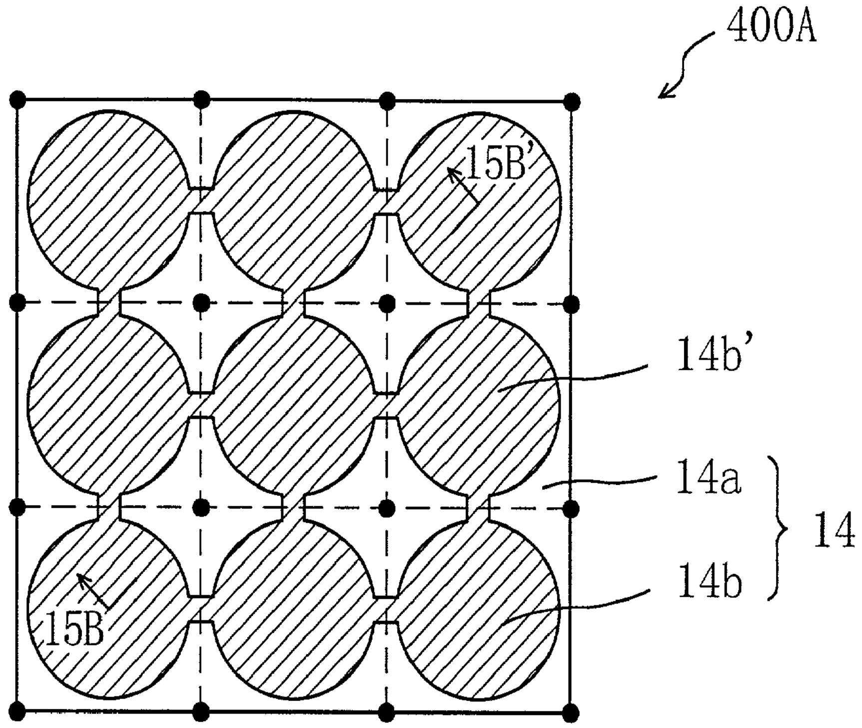


FIG. 15B

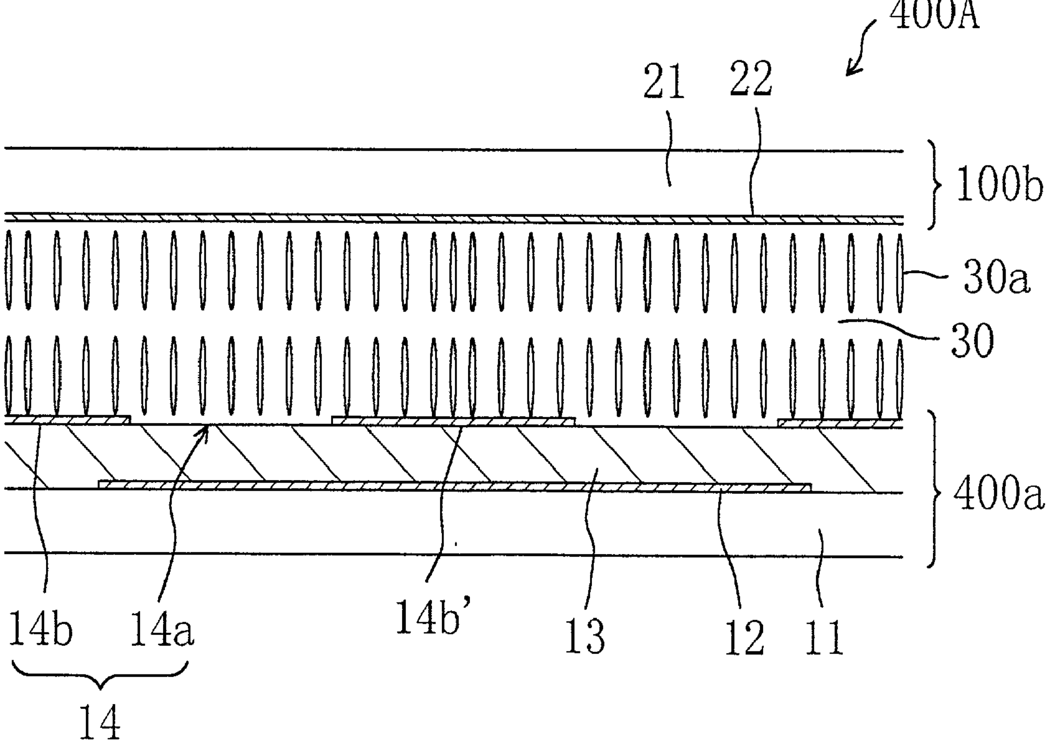


FIG. 16A

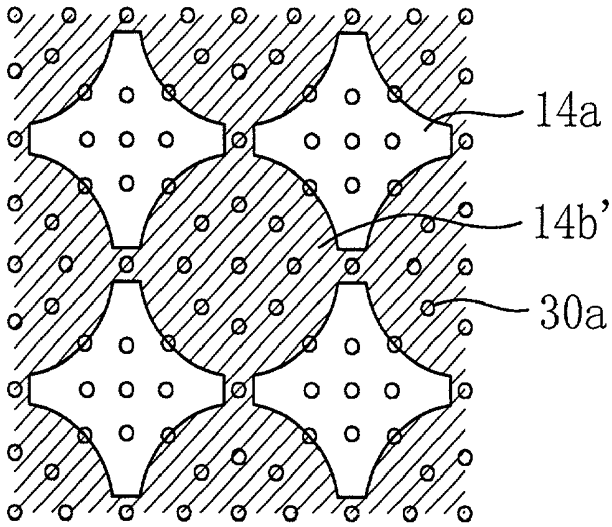


FIG. 16B

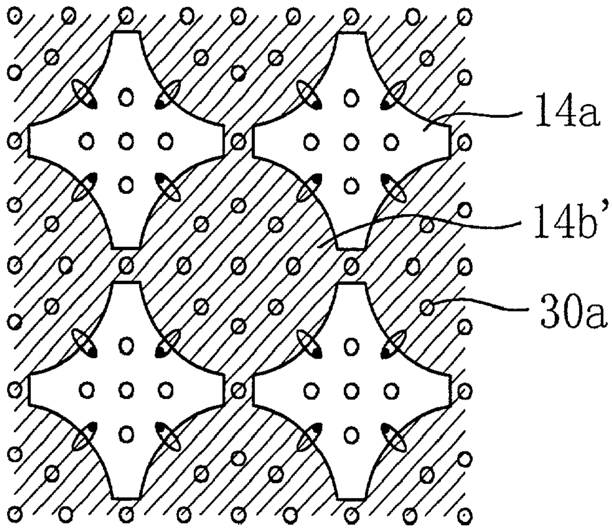
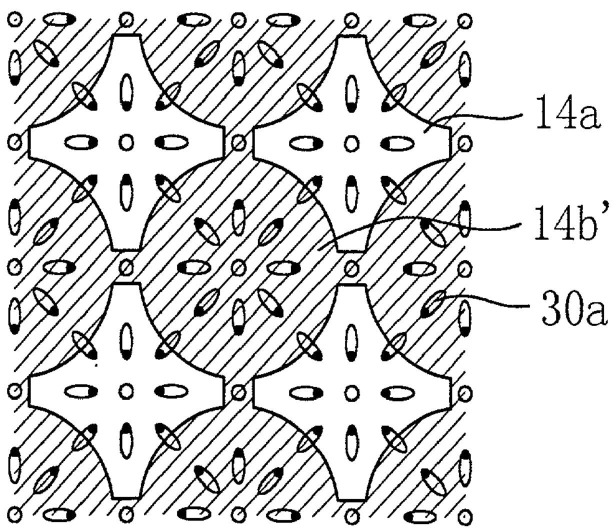


FIG. 16C



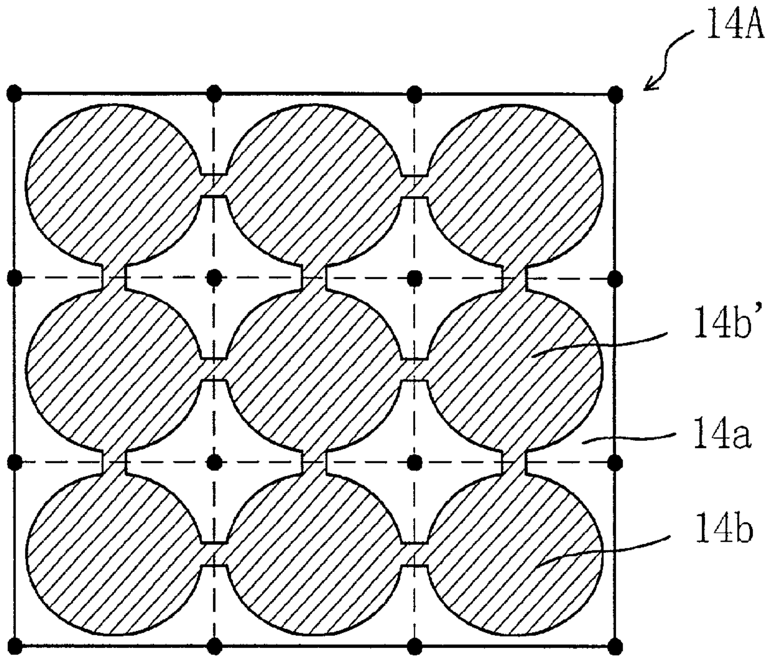


FIG. 17A

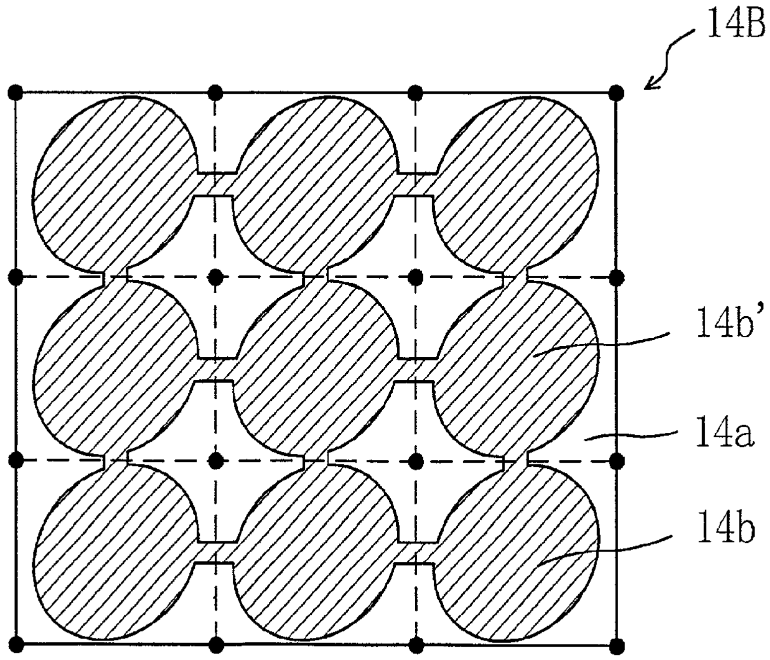


FIG. 17B

FIG. 18A

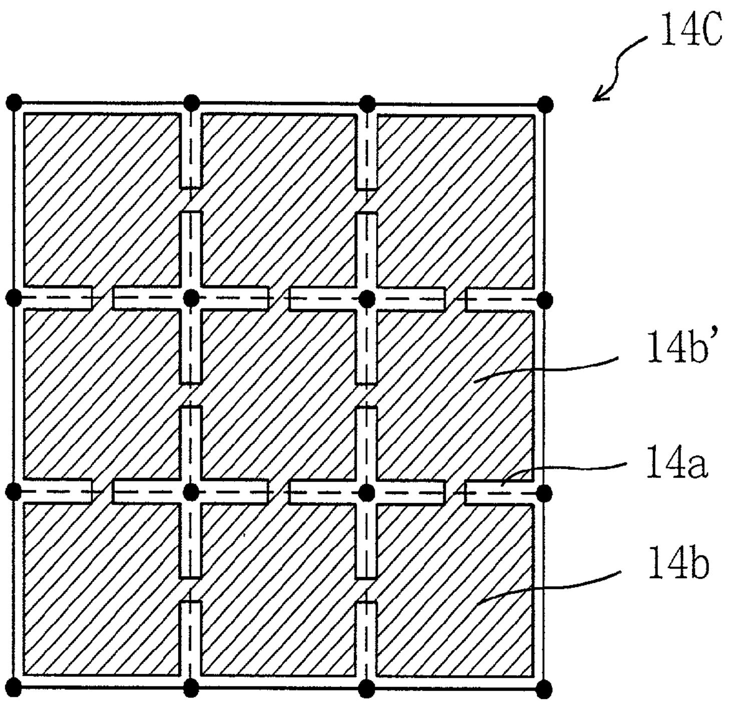


FIG. 18B

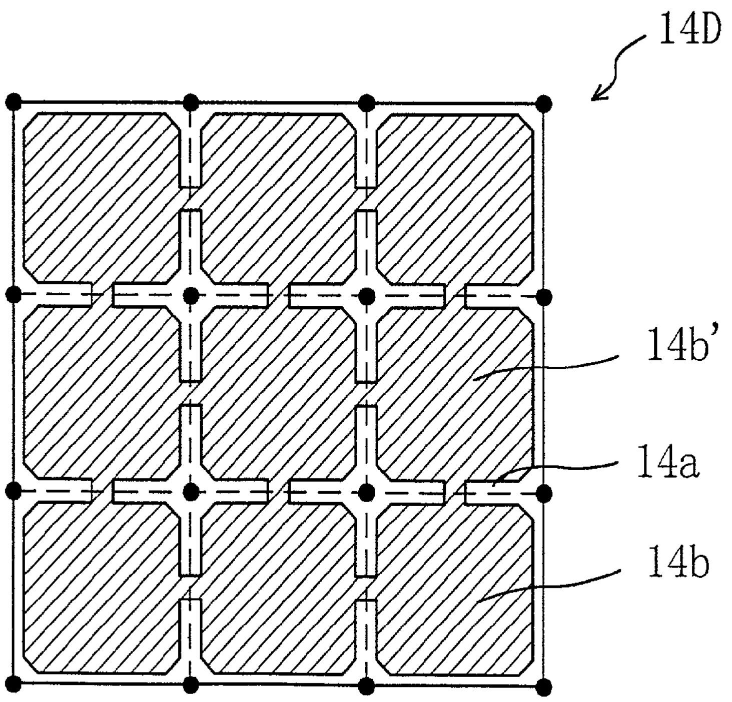


FIG. 19A

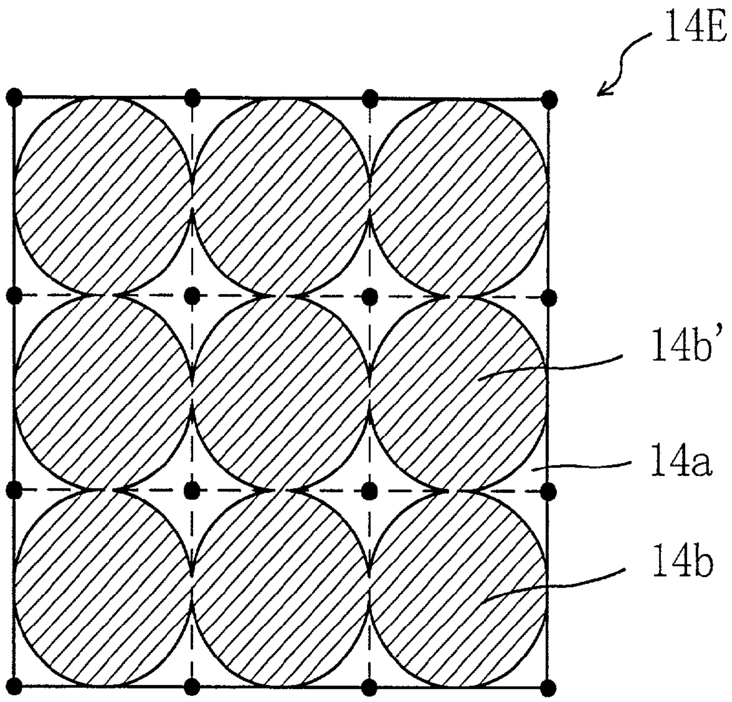


FIG. 19B

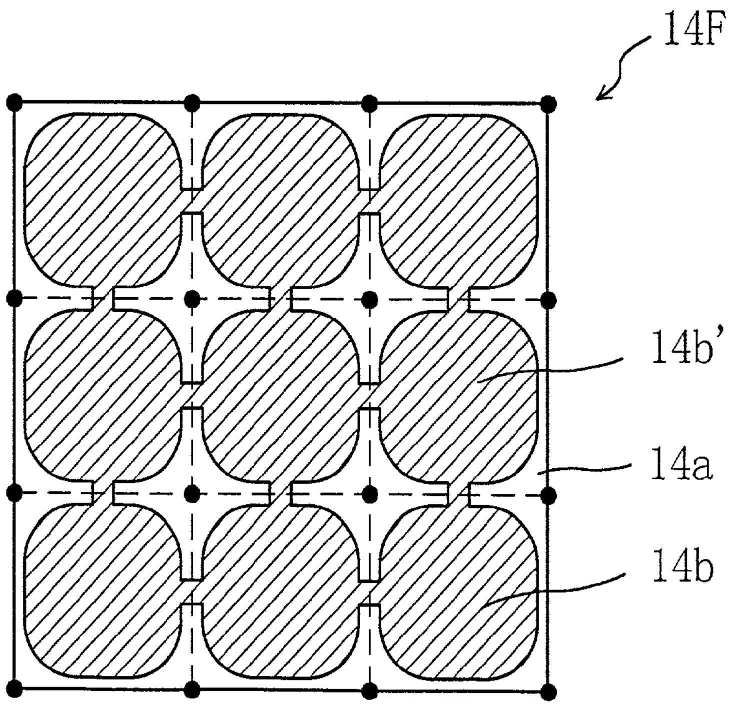
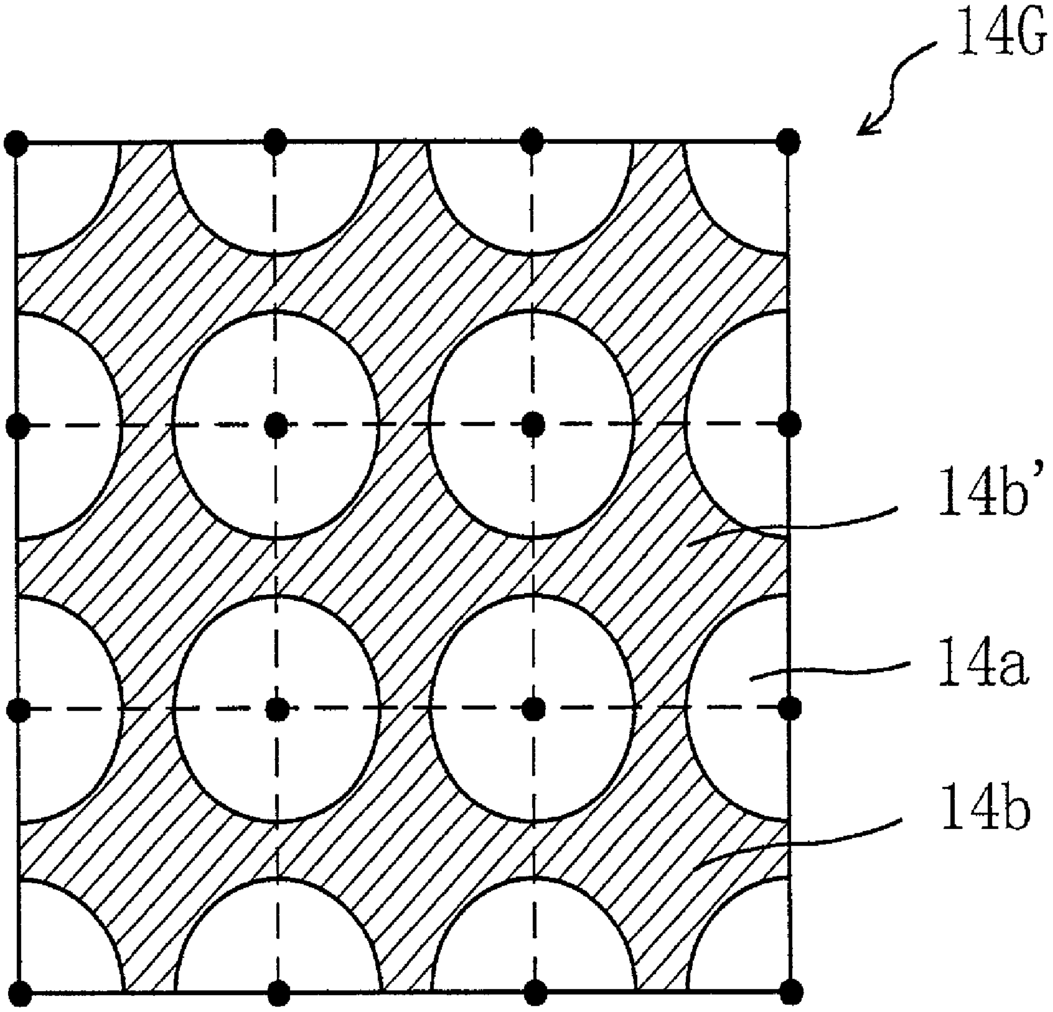


FIG. 20



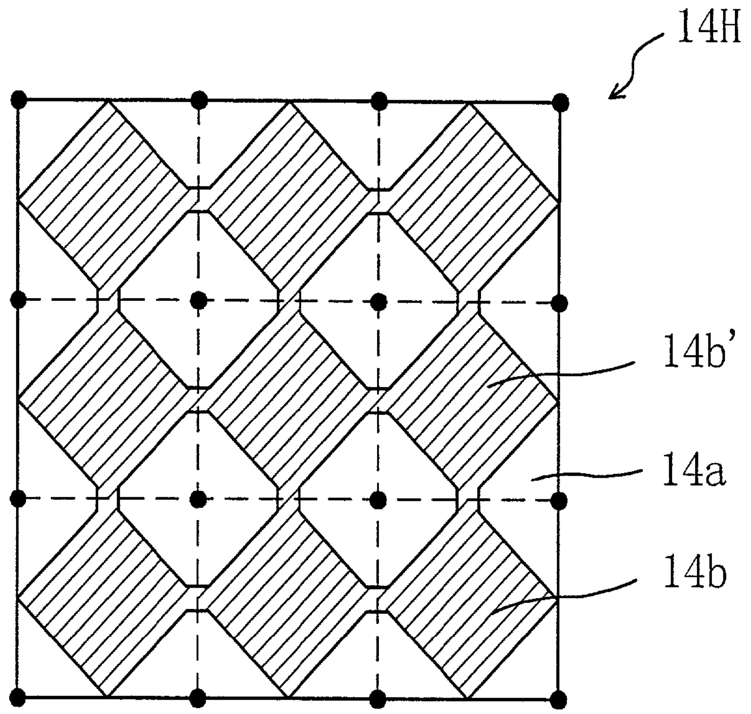


FIG. 21A

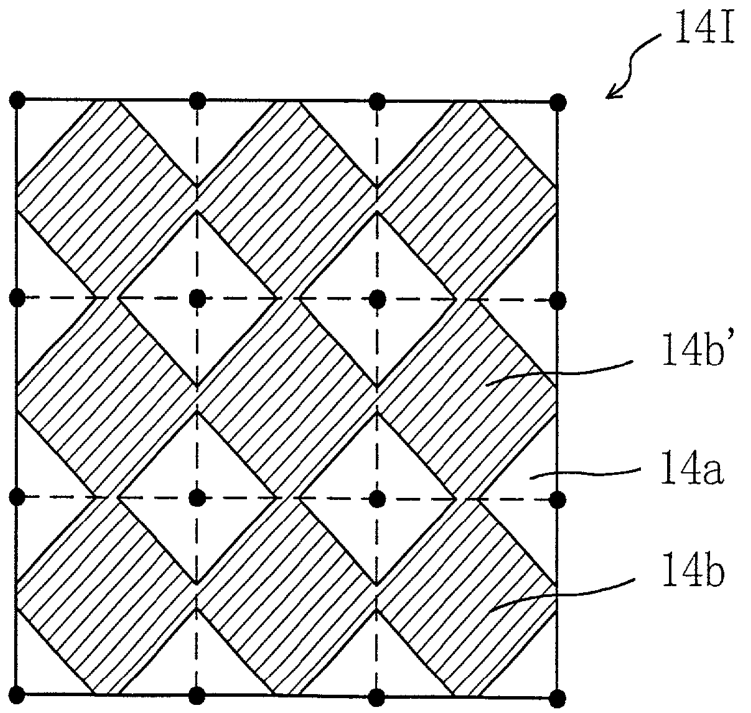


FIG. 21B

FIG. 22A

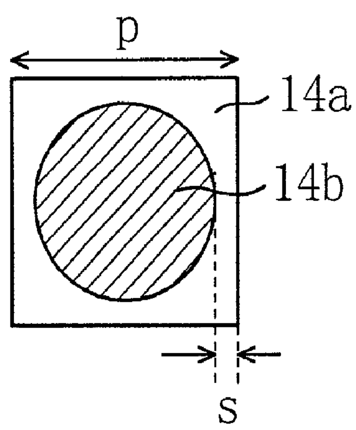


FIG. 22B

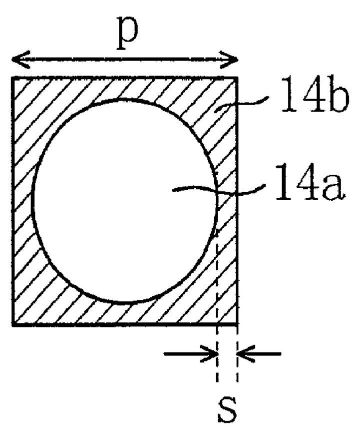


FIG. 22C

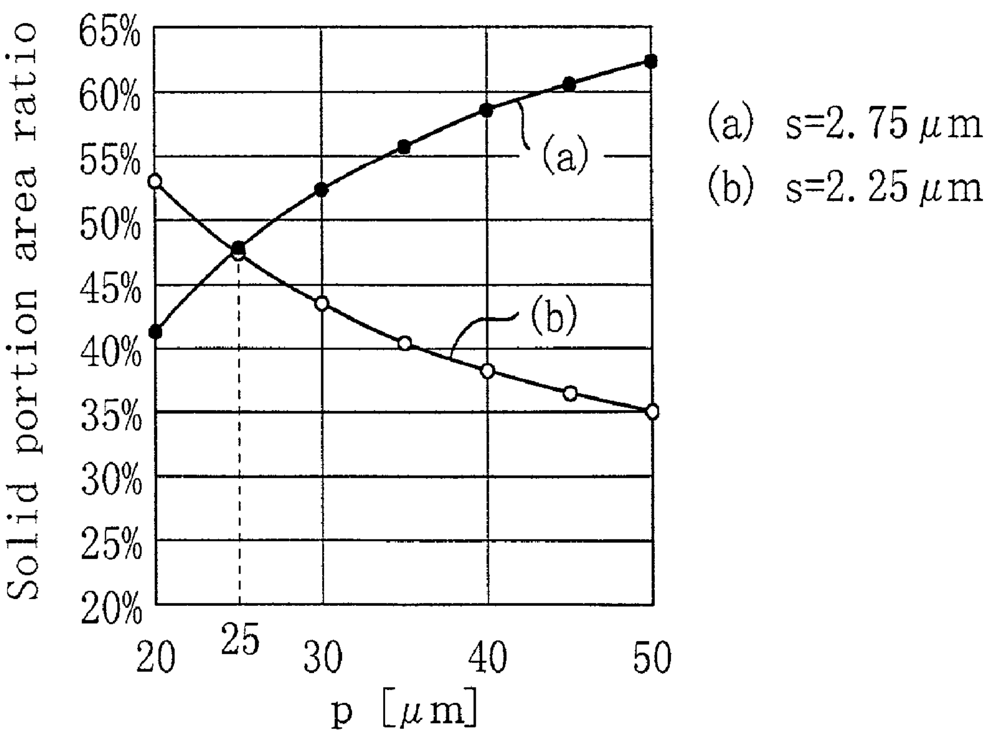


FIG. 23A

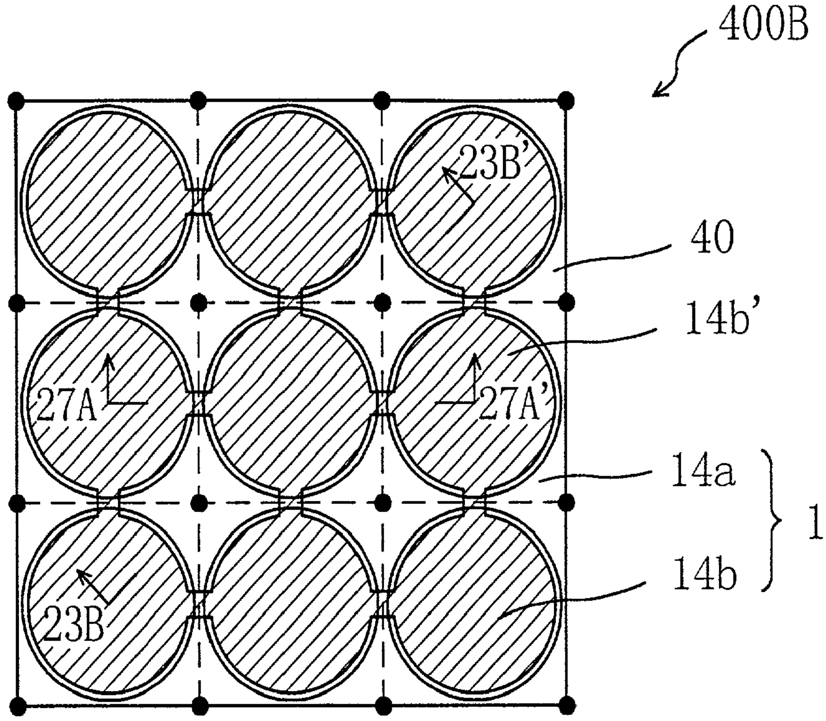


FIG. 23B

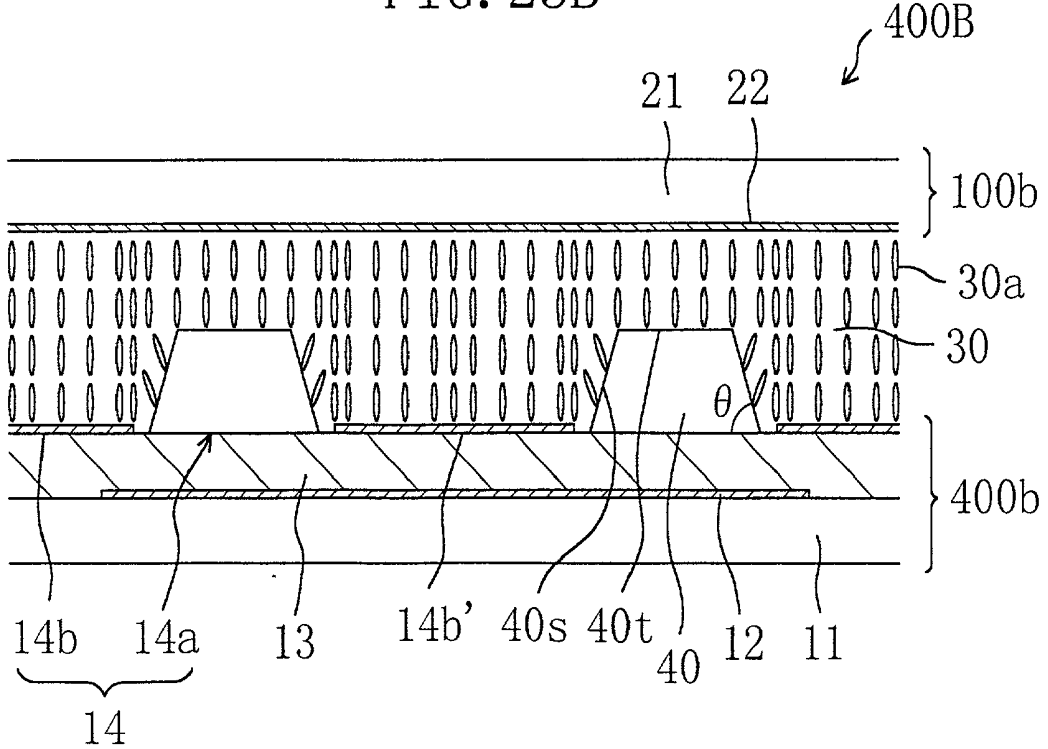


FIG. 24A

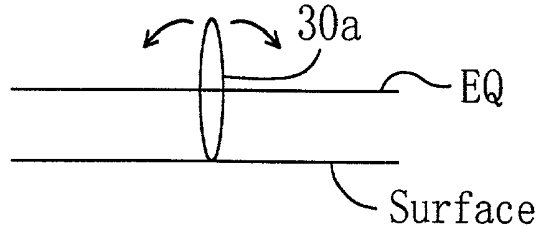


FIG. 24B

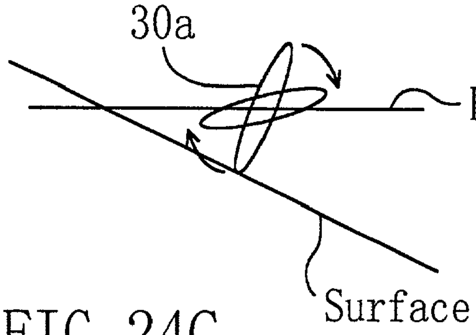


FIG. 24C

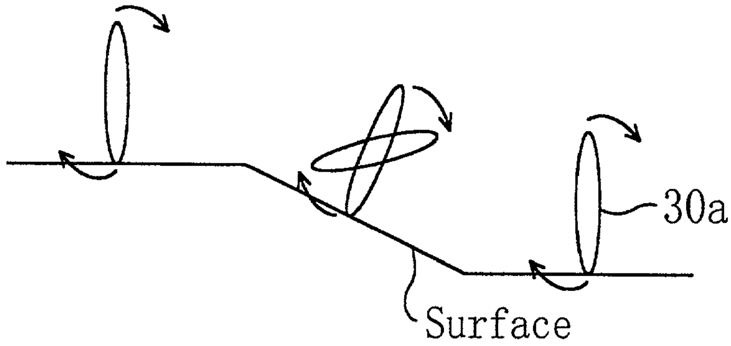


FIG. 24D

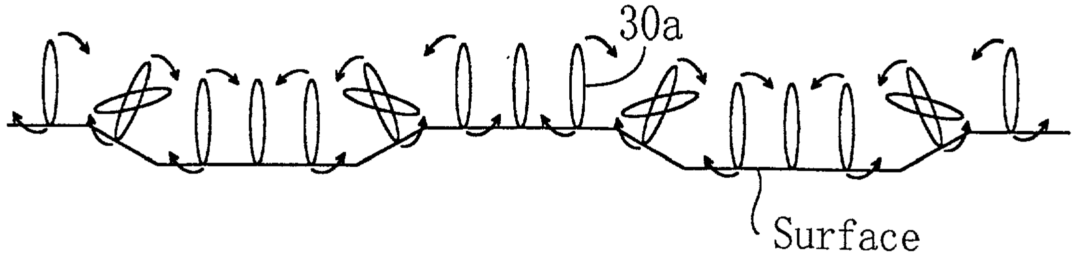


FIG. 25A

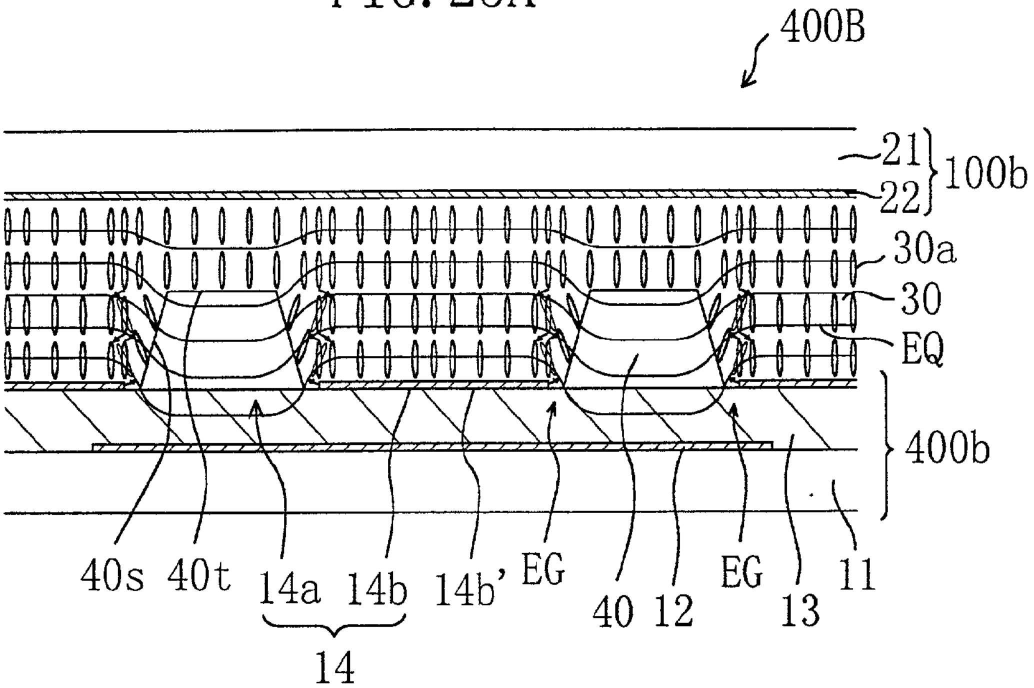


FIG. 25B

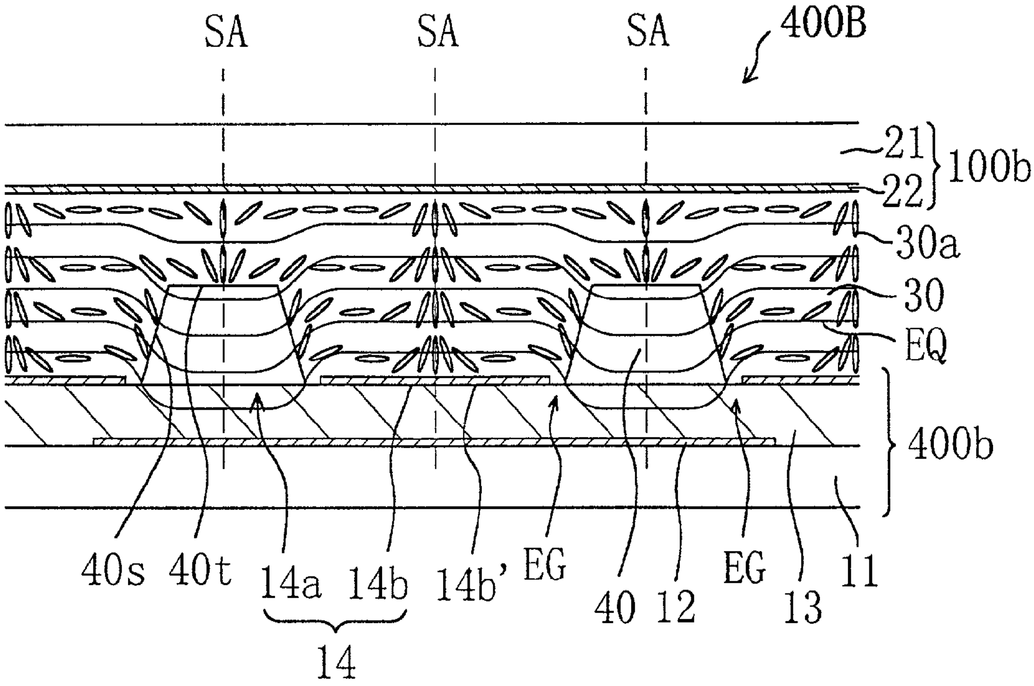


FIG. 26A

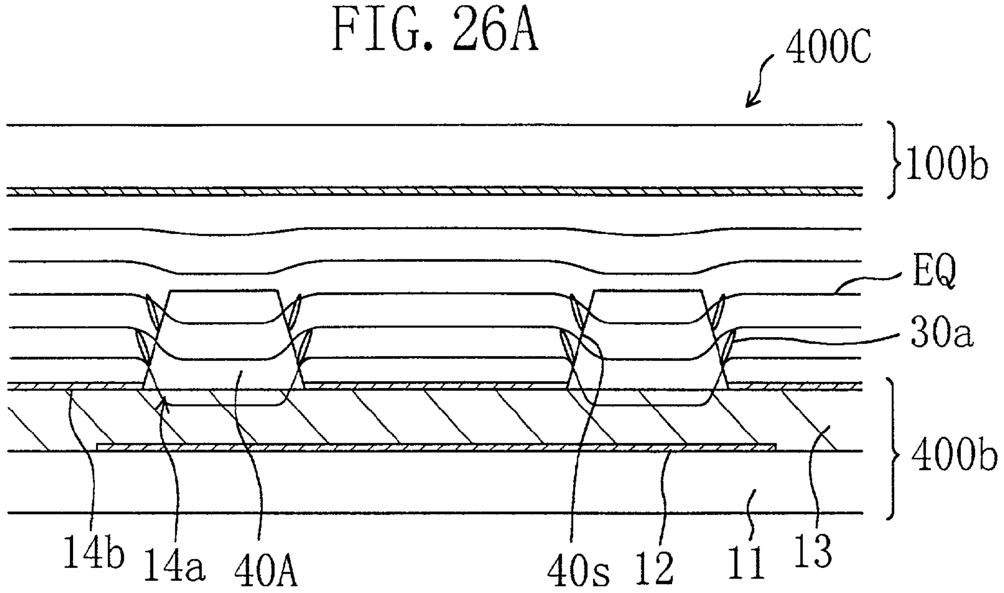


FIG. 26B

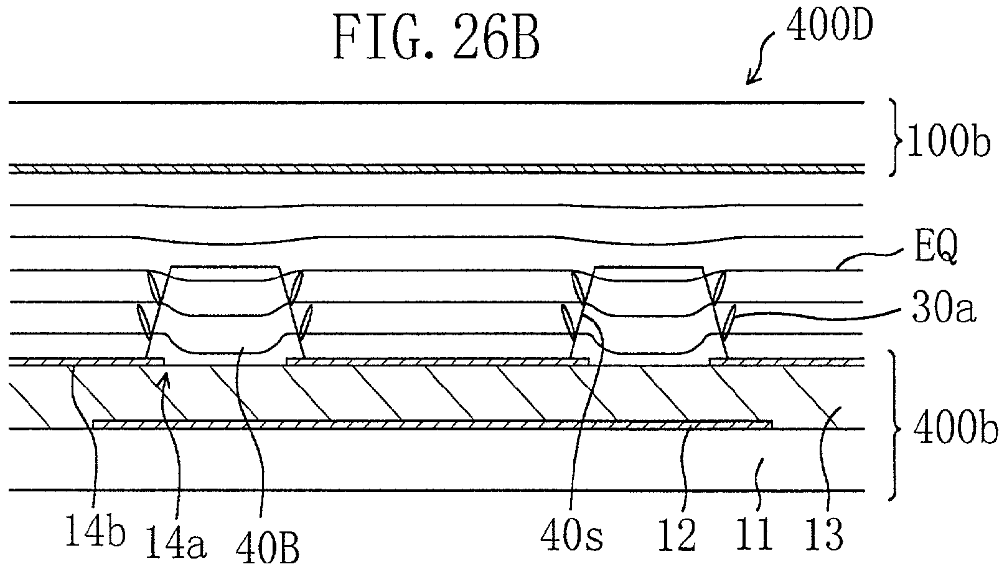


FIG. 26C

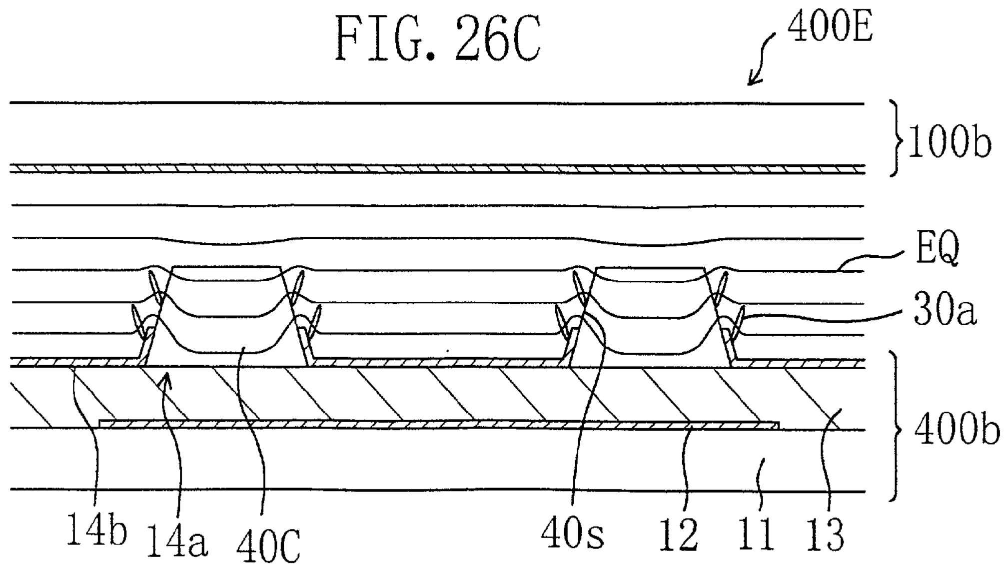


FIG. 27

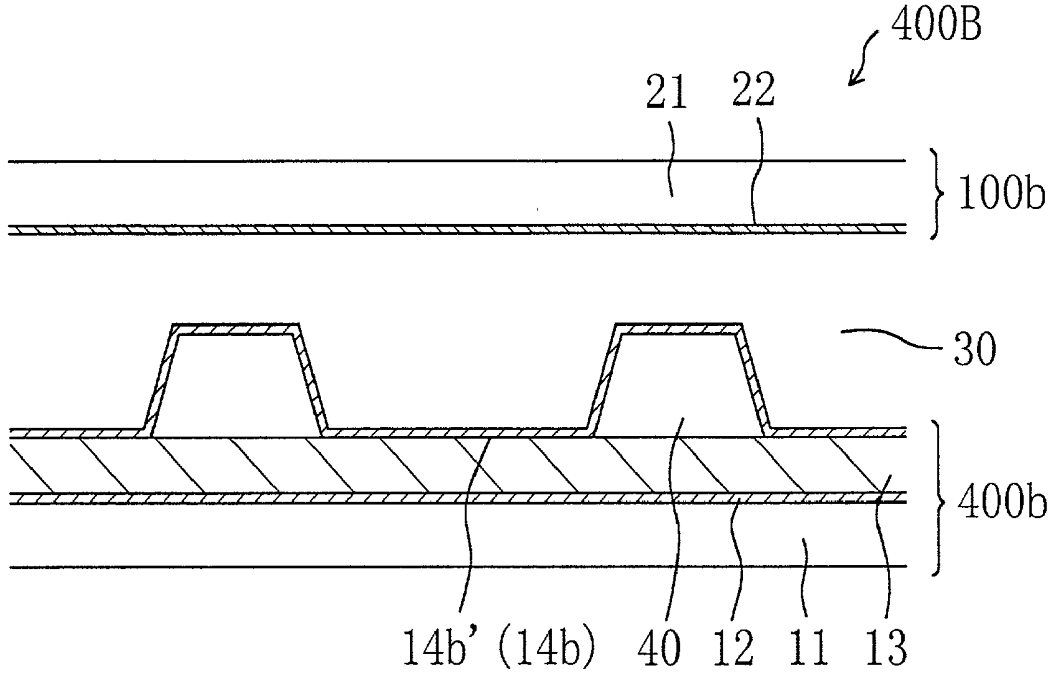


FIG. 28A

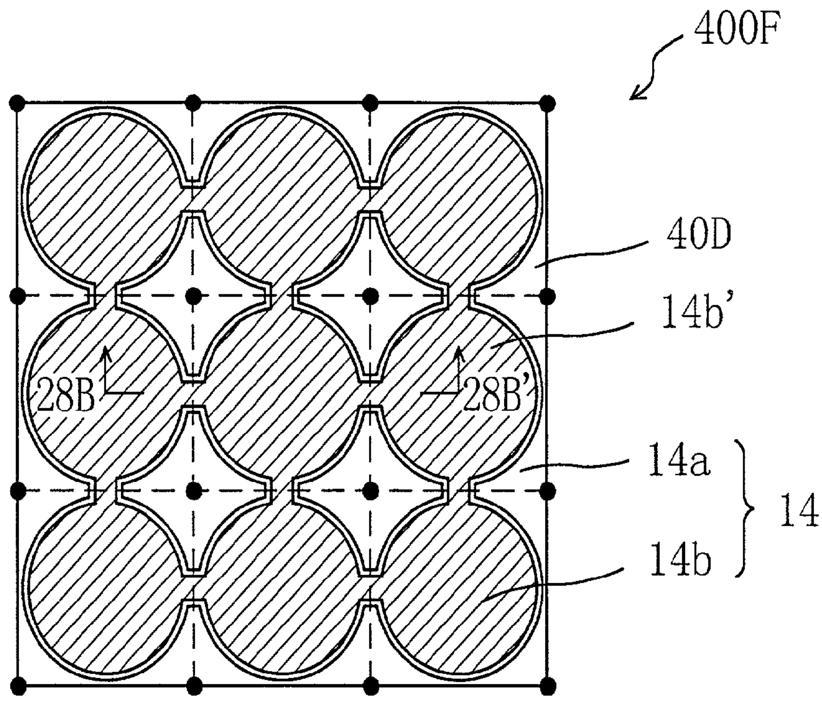


FIG. 28B

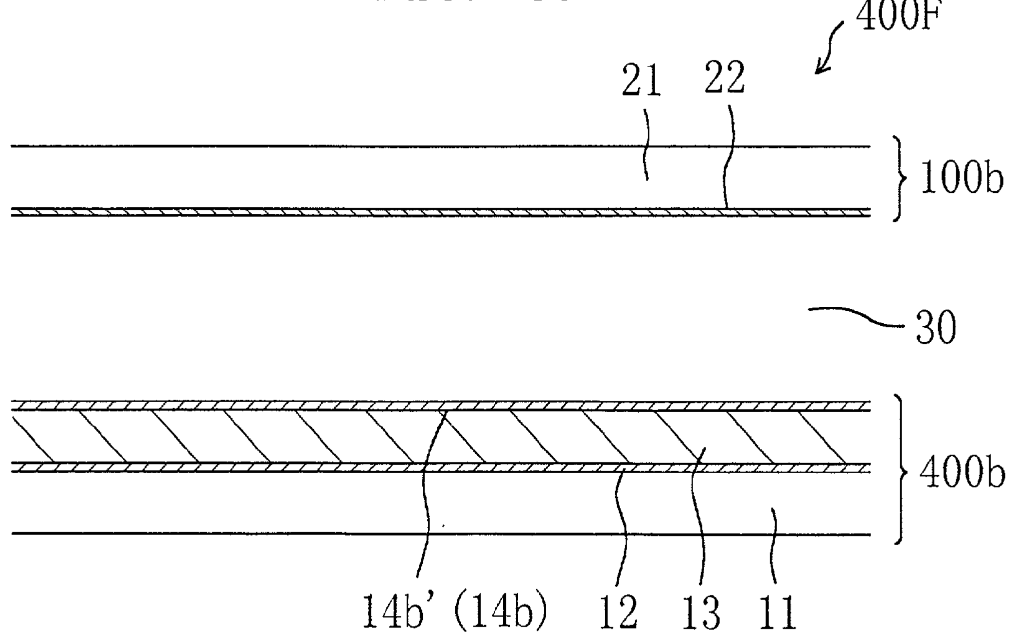


FIG. 29A

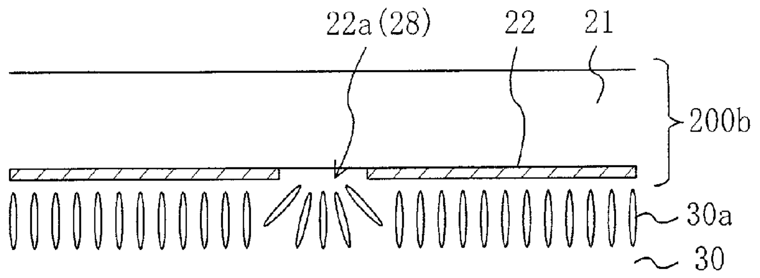


FIG. 29B

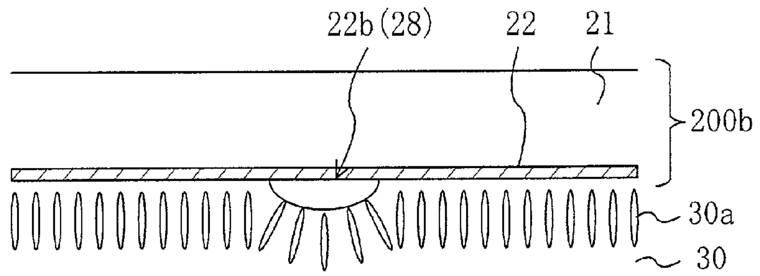


FIG. 29C

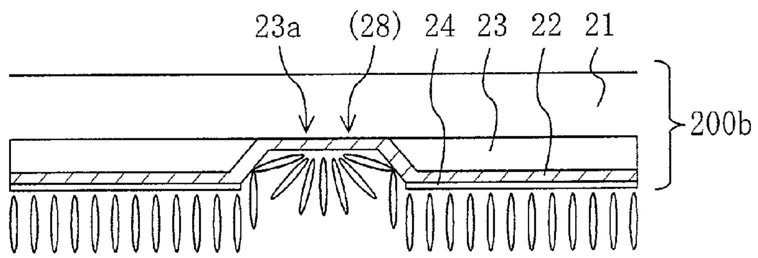


FIG. 29D

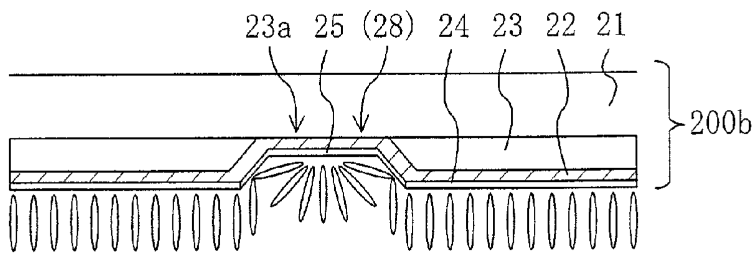


FIG. 29E

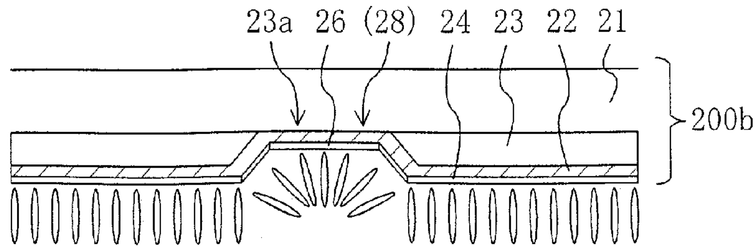


FIG. 30A

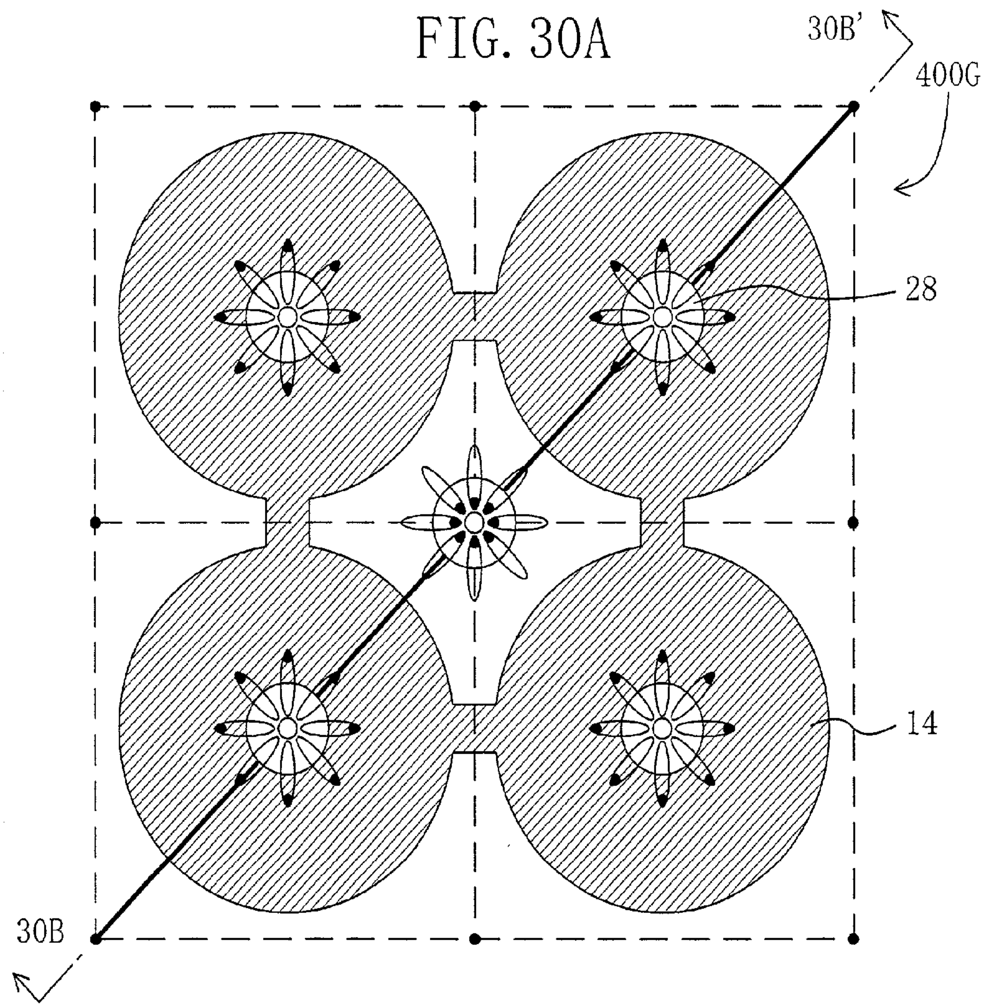


FIG. 30B

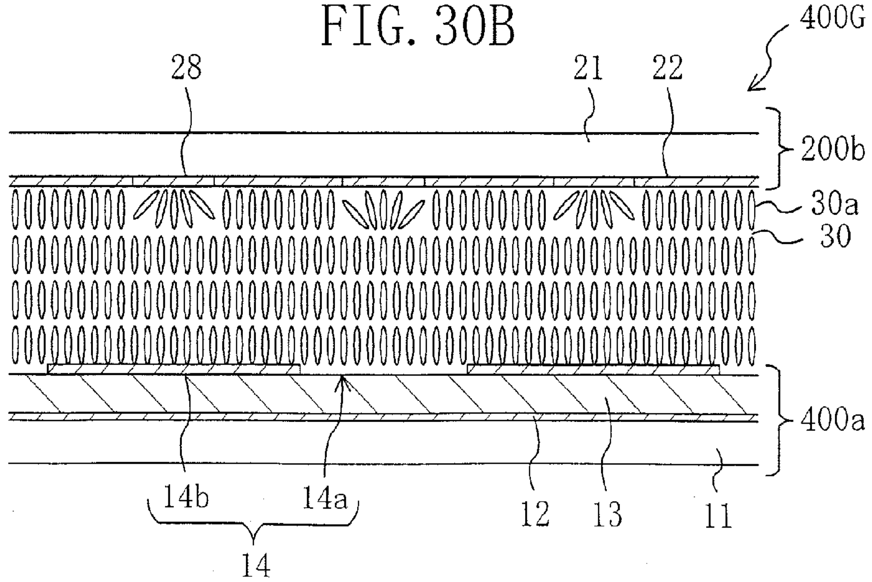


FIG. 31A

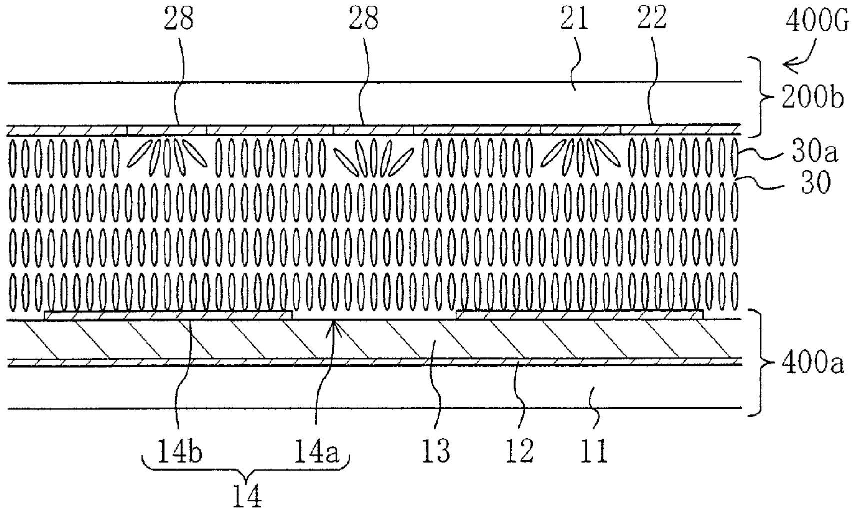


FIG. 31B

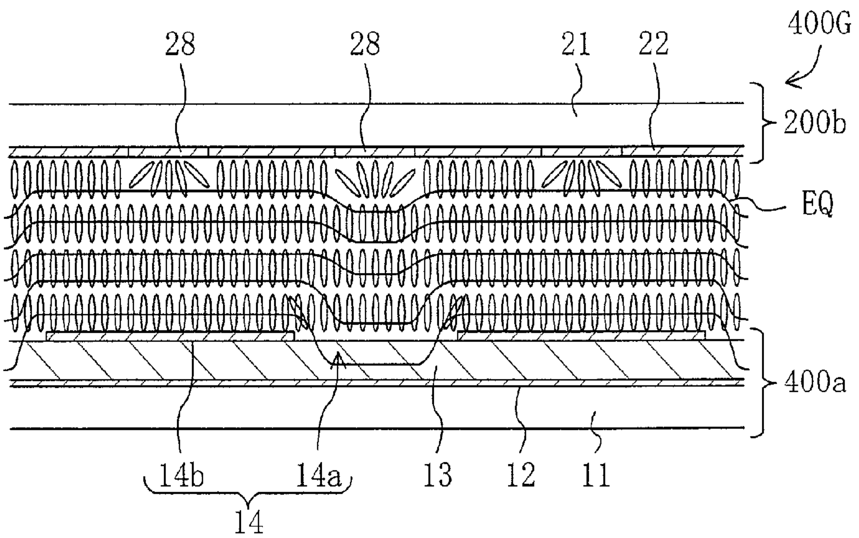


FIG. 31C

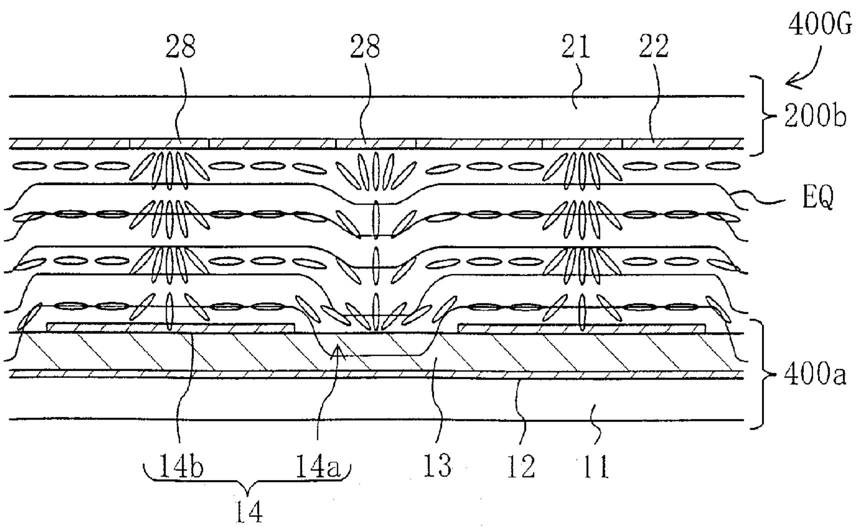


FIG. 32A

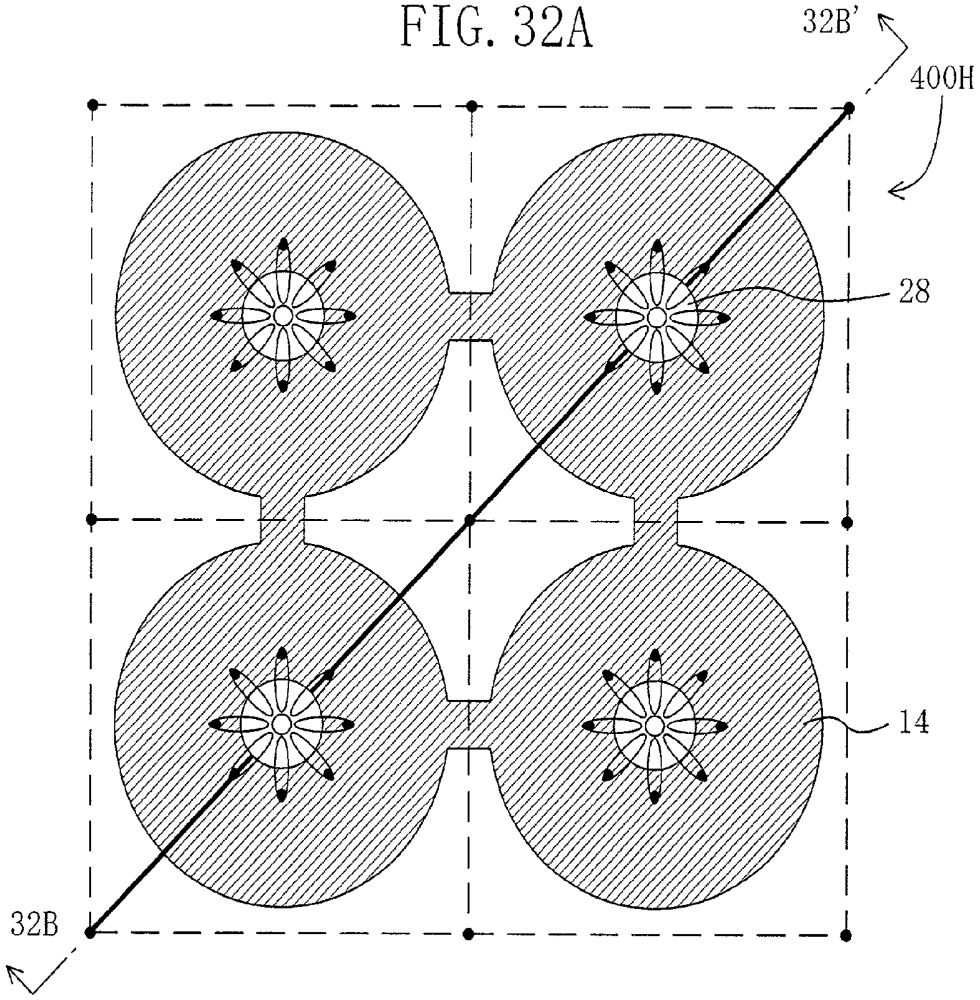
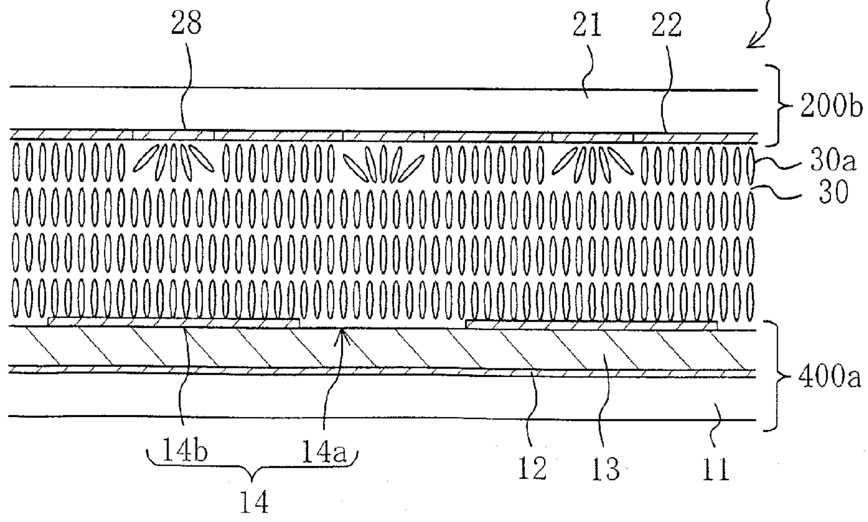


FIG. 32B



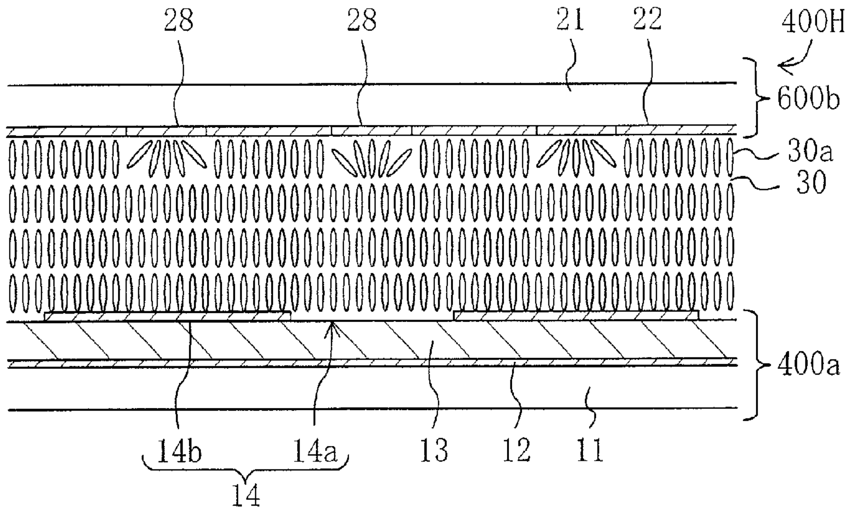


FIG. 33A

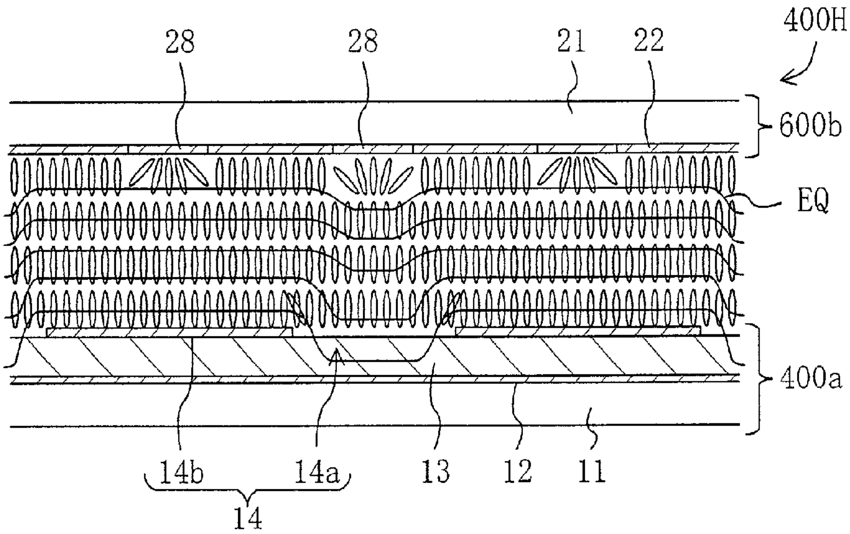


FIG. 33B

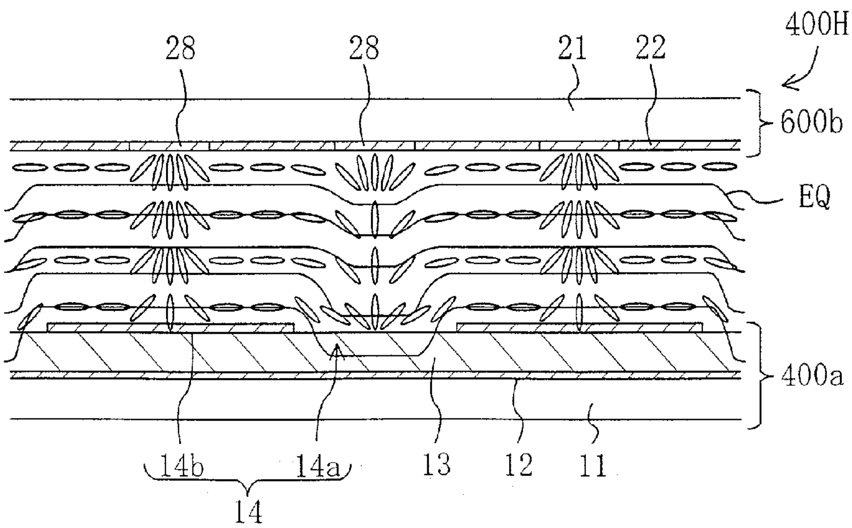


FIG. 33C

FIG. 34A

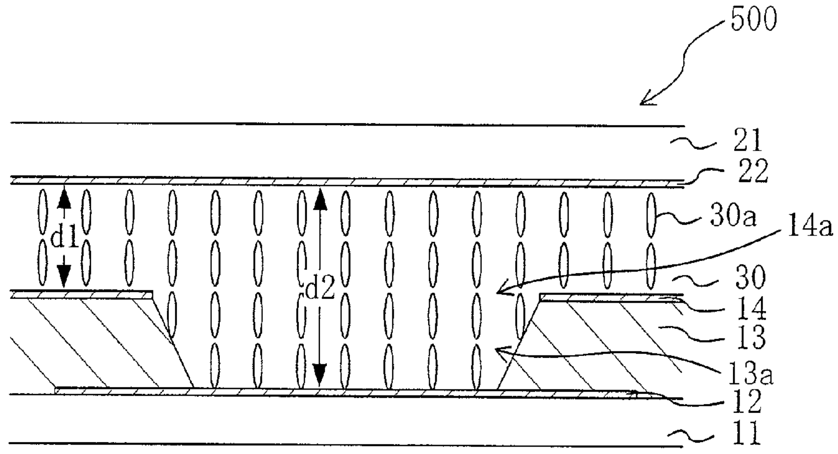


FIG. 34B

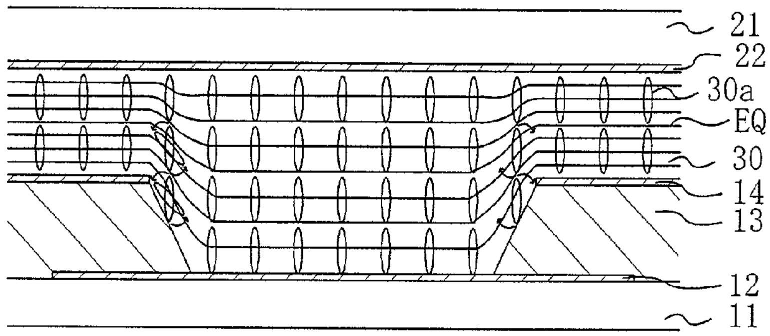


FIG. 34C

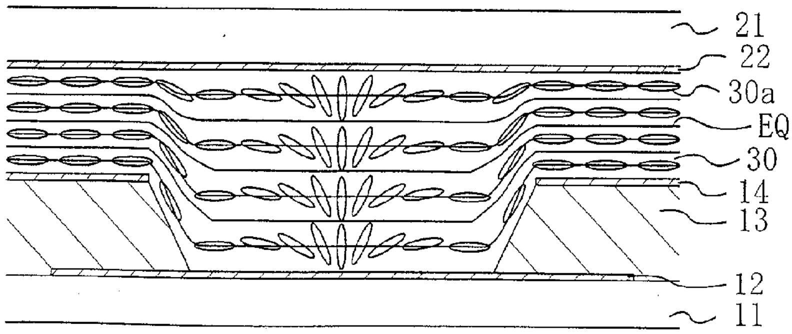


FIG. 35

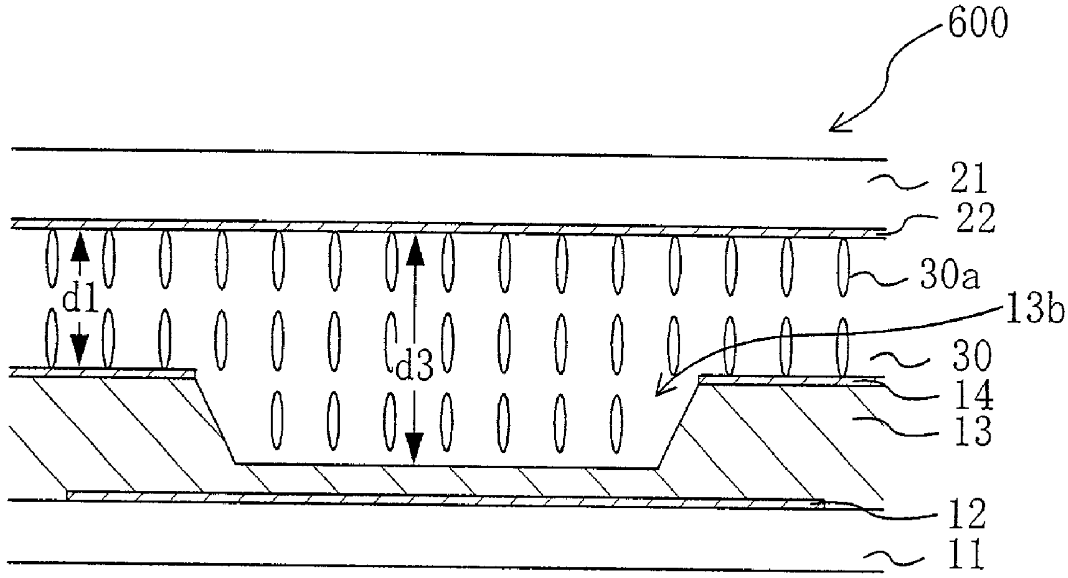


FIG. 36A

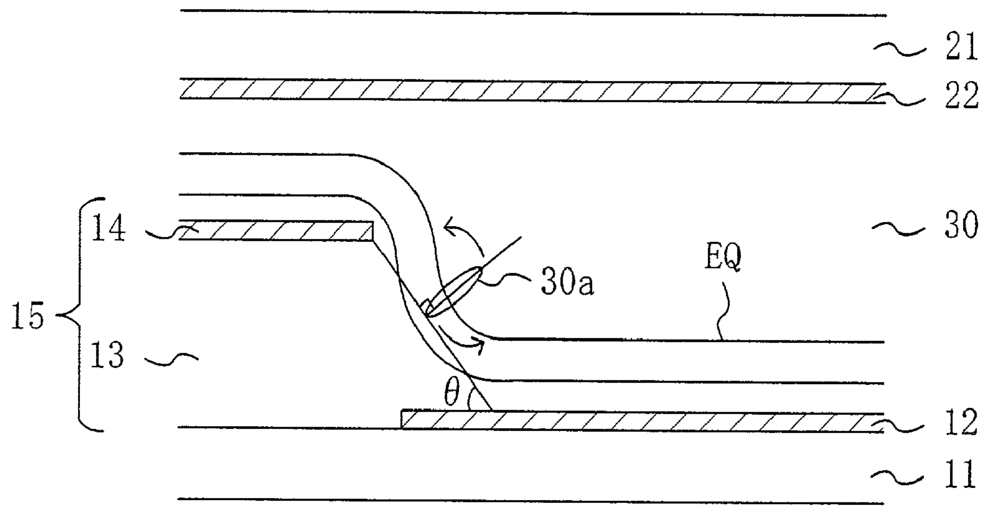


FIG. 36B

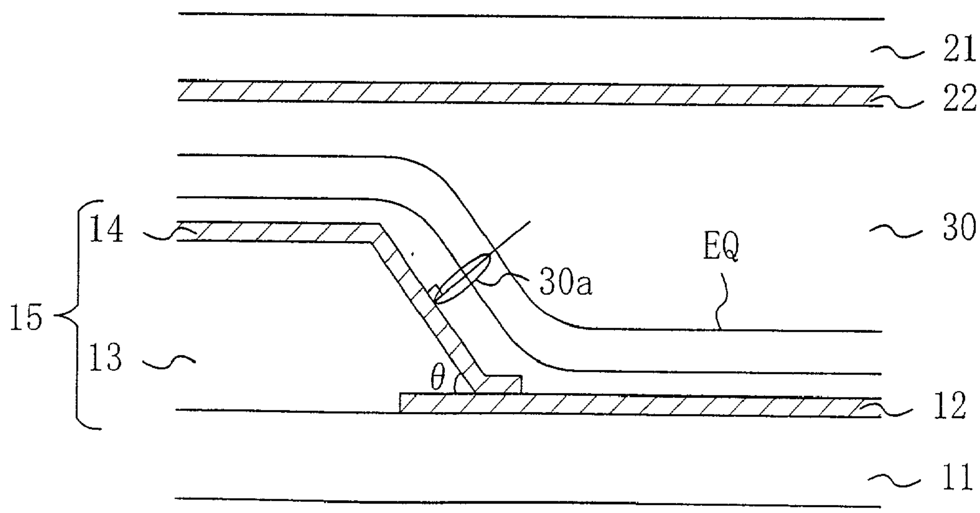


FIG. 37A

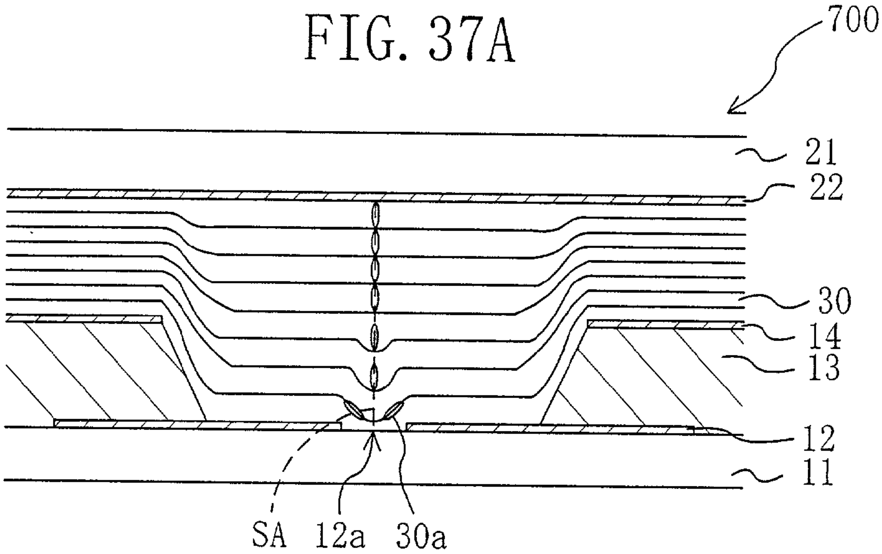


FIG. 37B

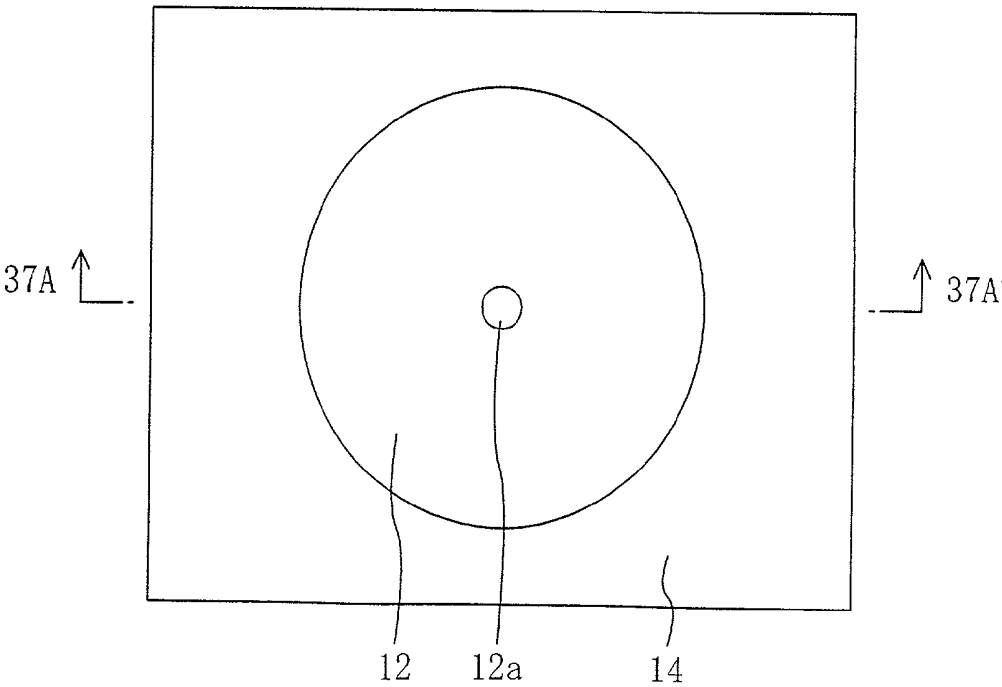


FIG. 38A

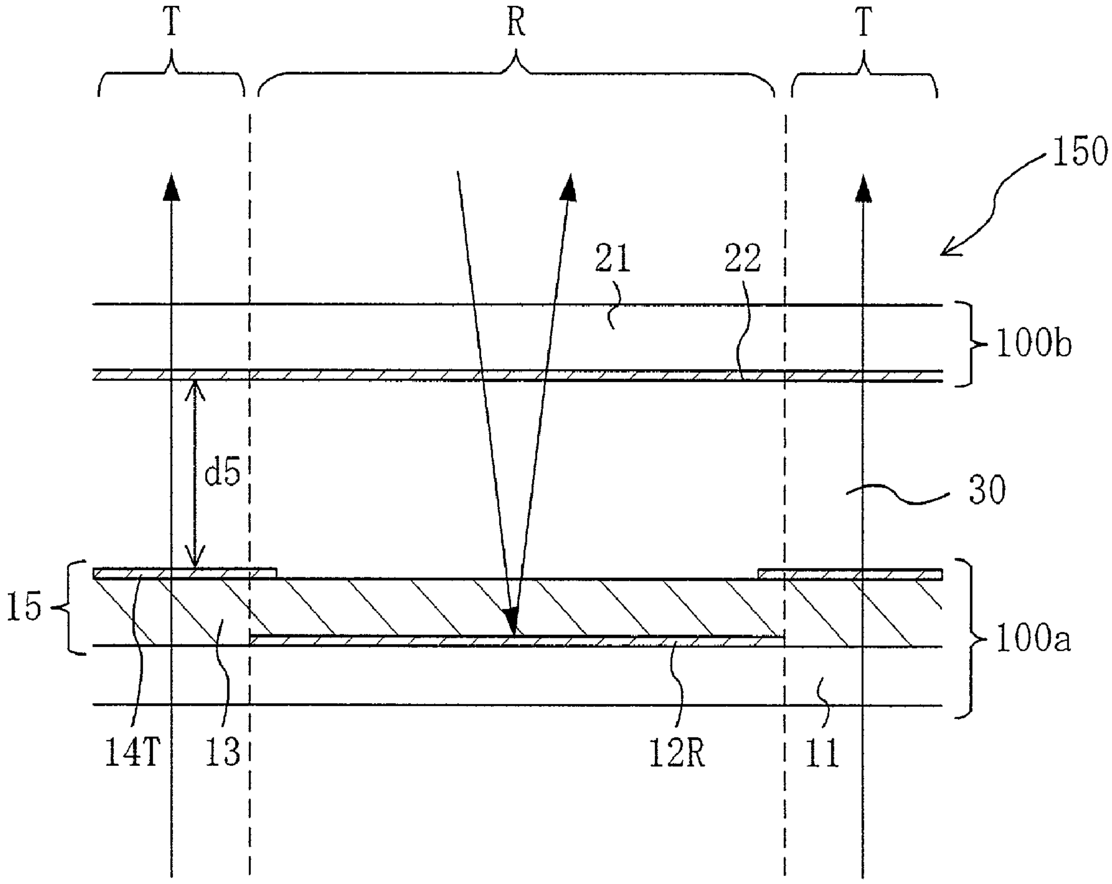


FIG. 38B

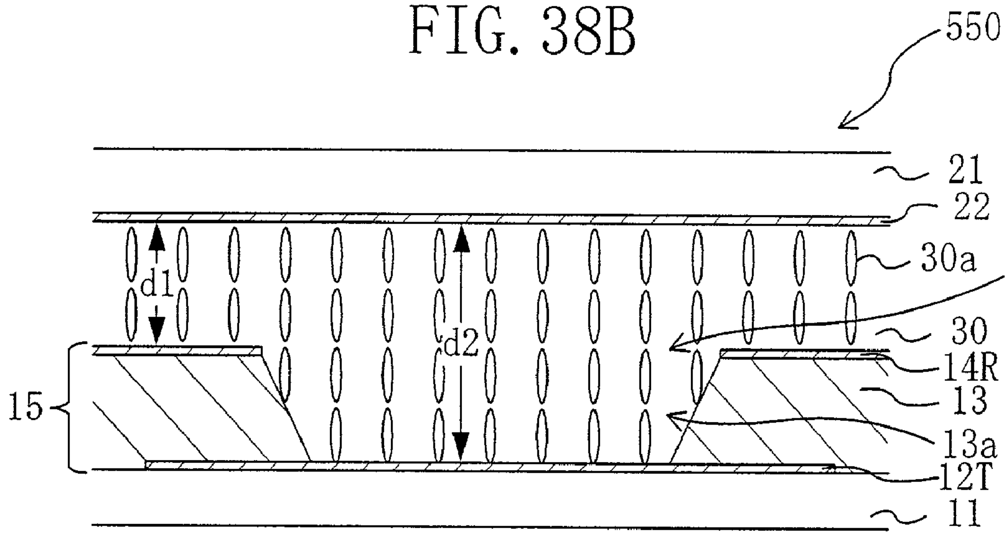


FIG. 38C

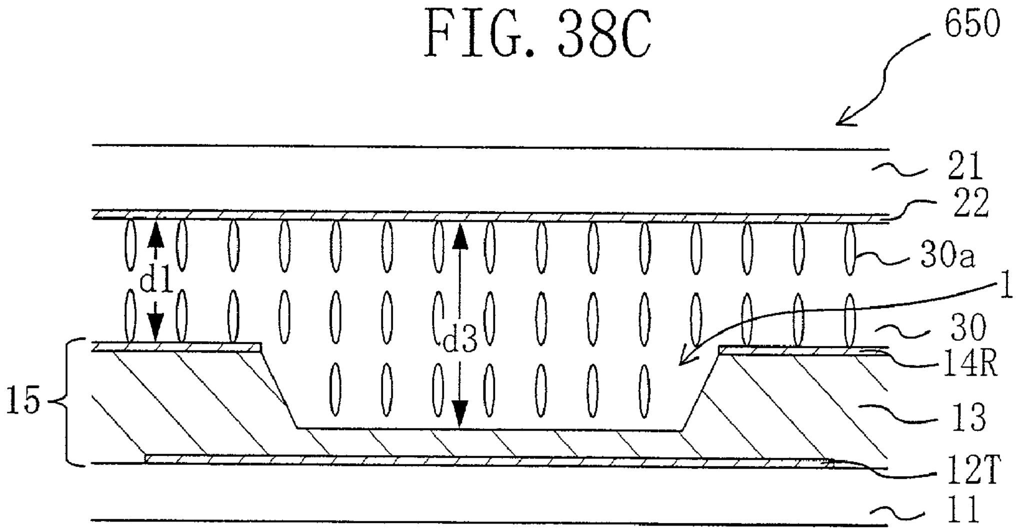


FIG. 39A

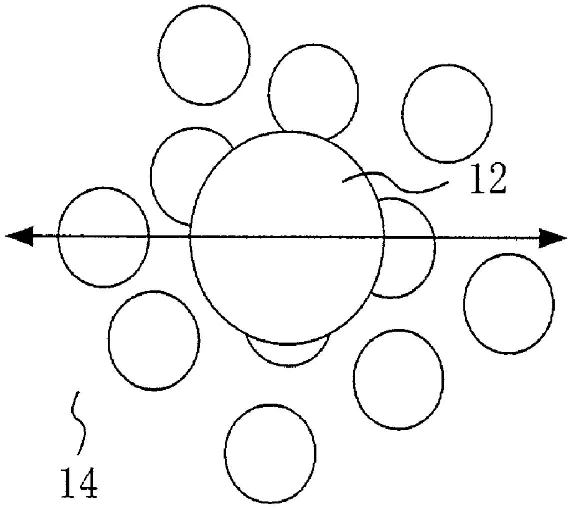


FIG. 39B

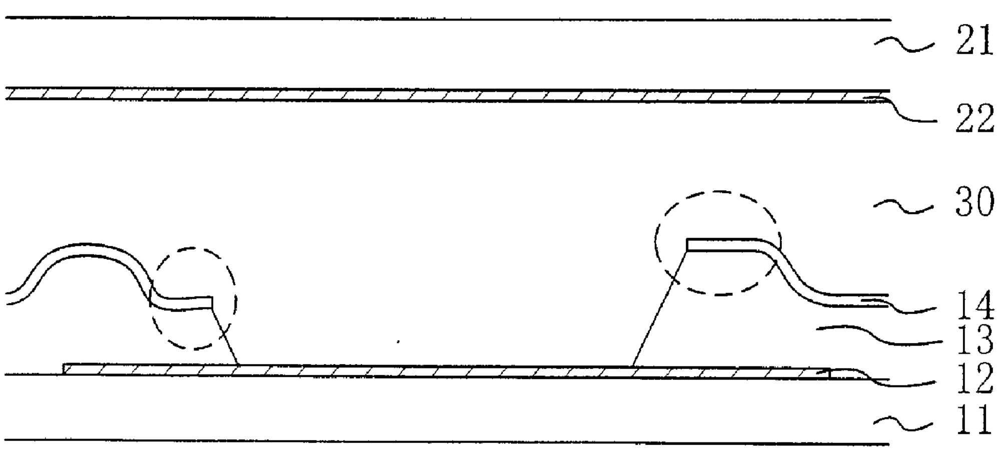


FIG. 40A

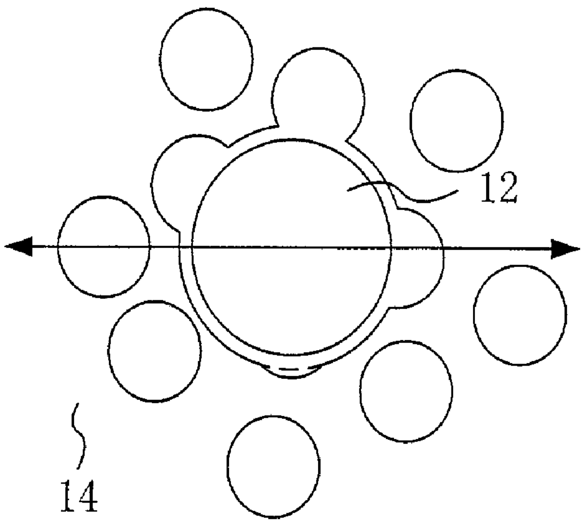


FIG. 40B

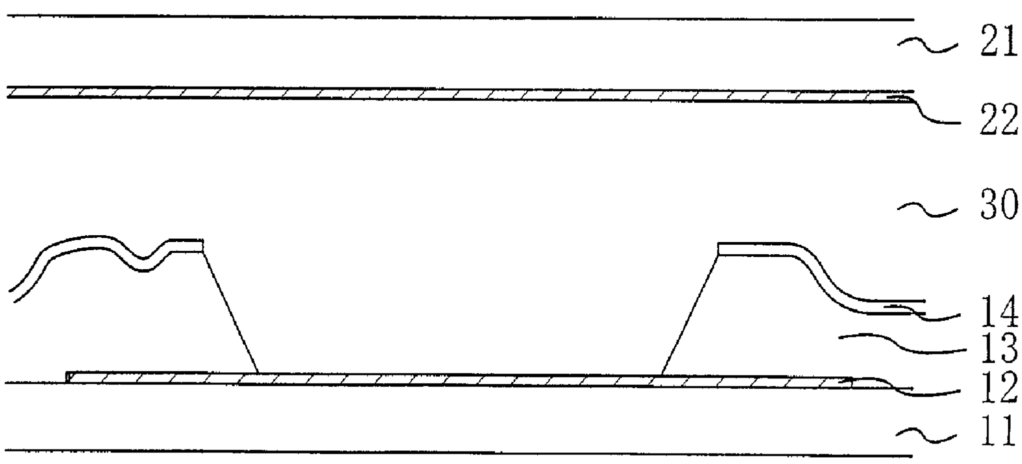


FIG. 41A

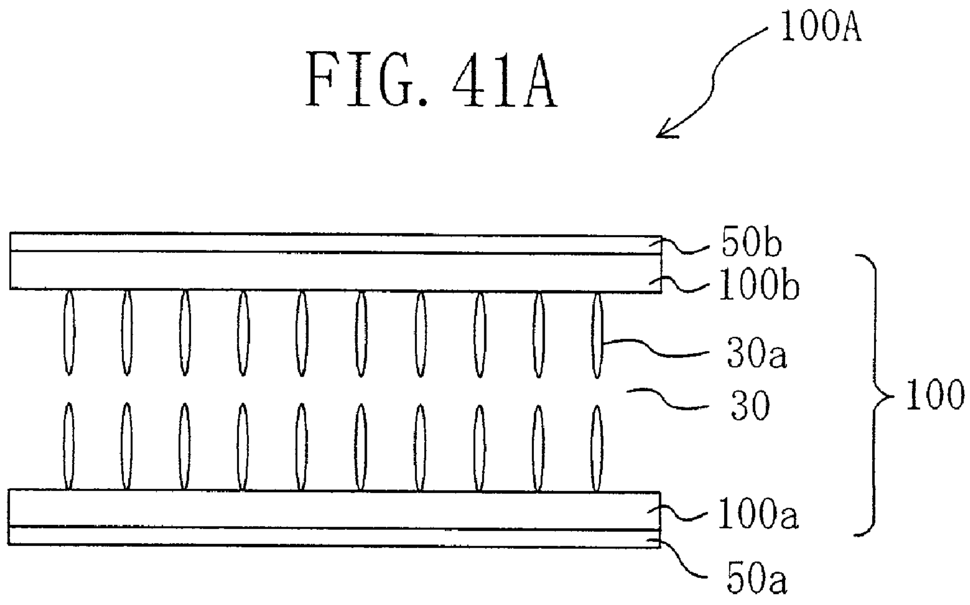


FIG. 41B

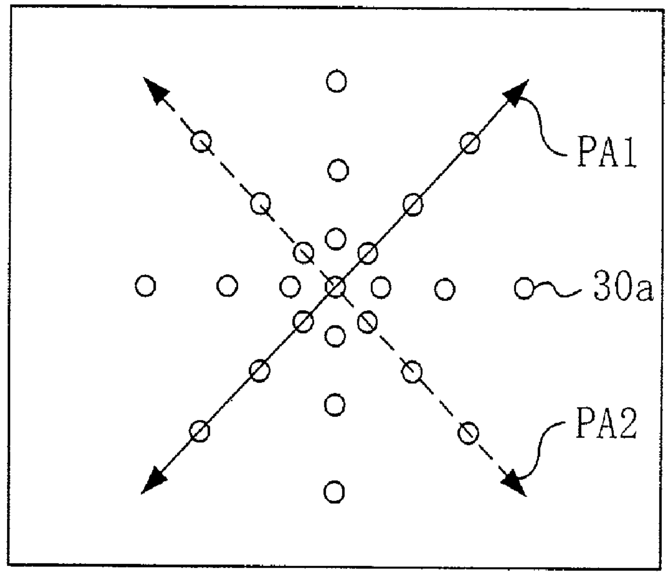


FIG. 42A

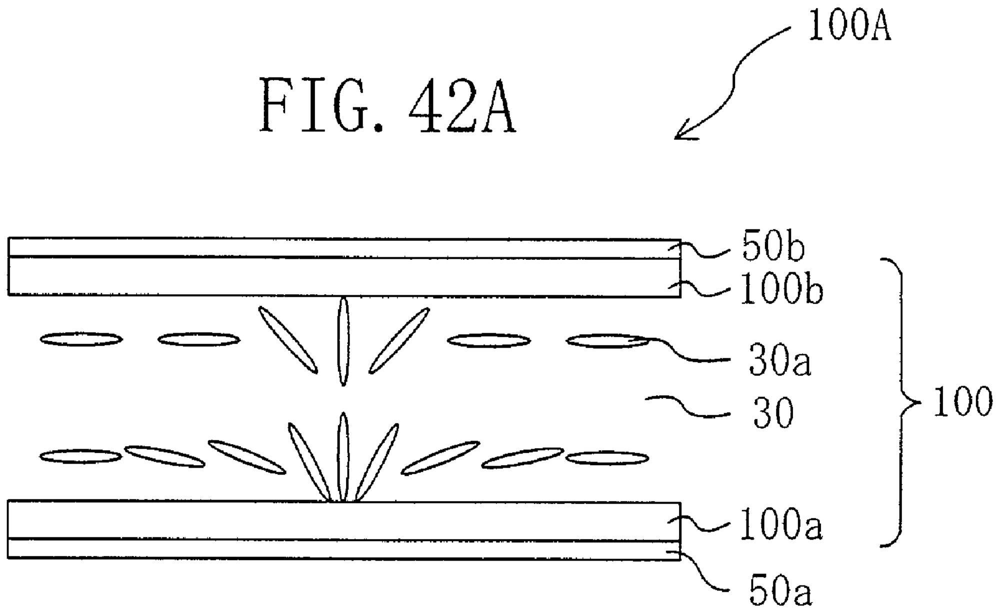


FIG. 42B

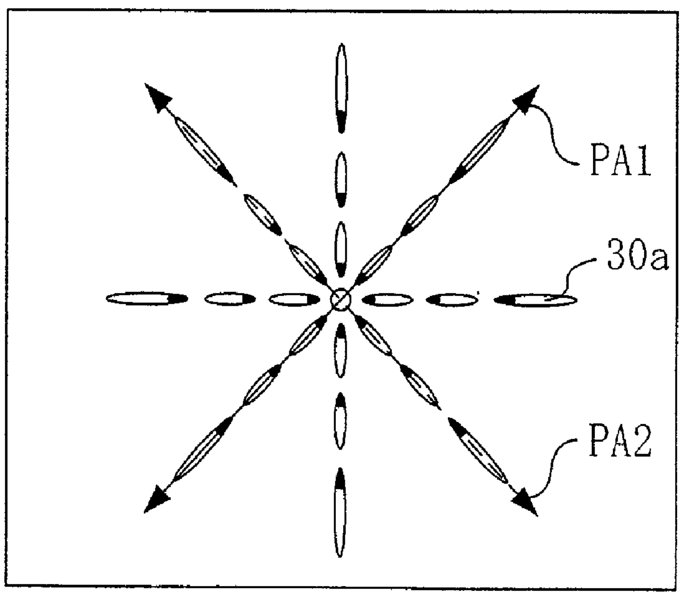


FIG. 43A

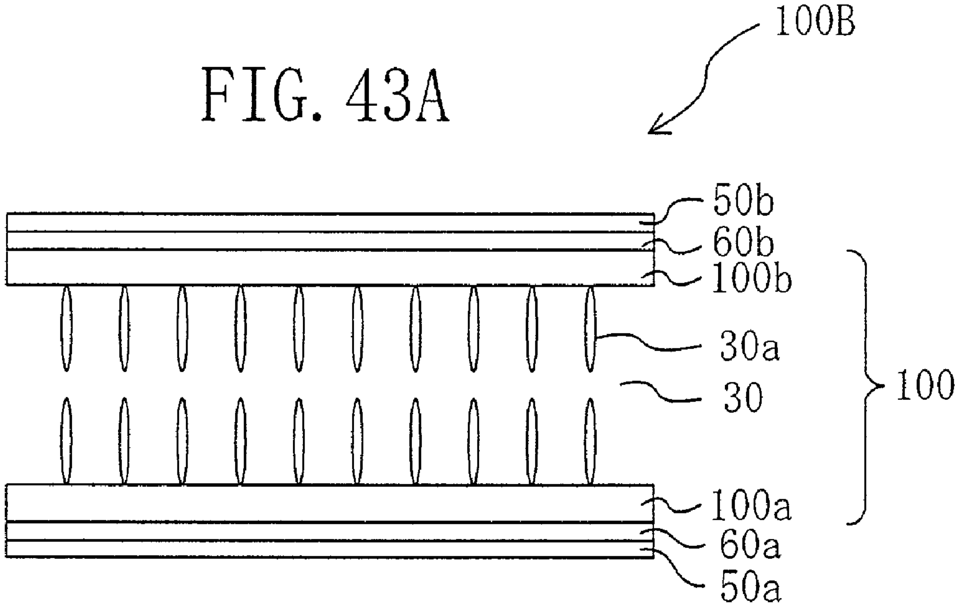


FIG. 43B

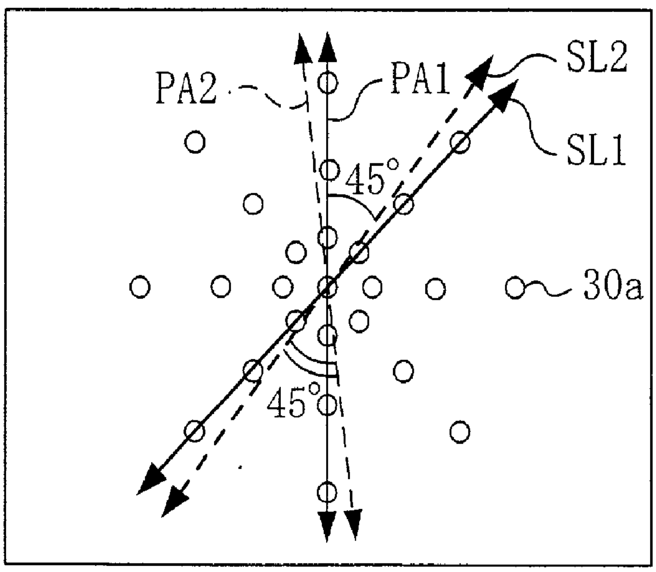


FIG. 44A

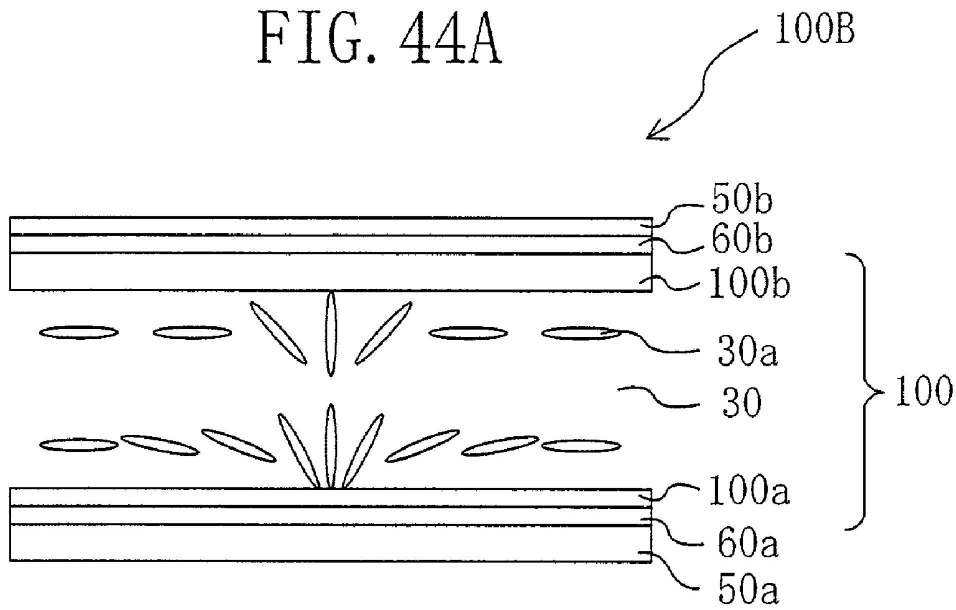


FIG. 44B

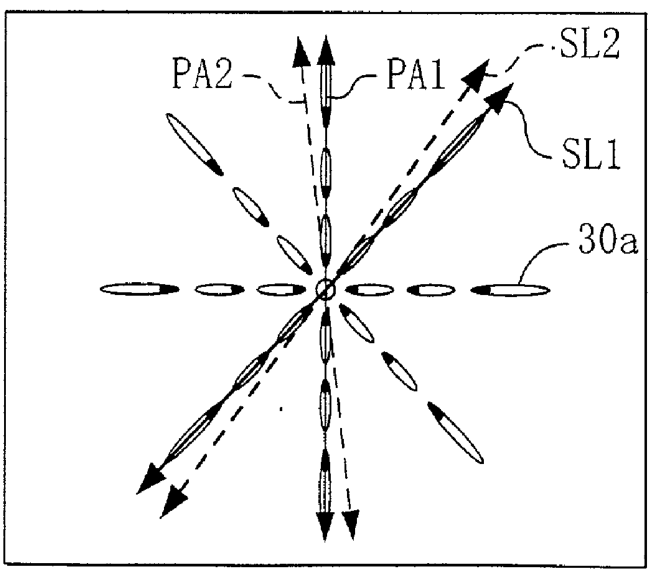


FIG. 45A

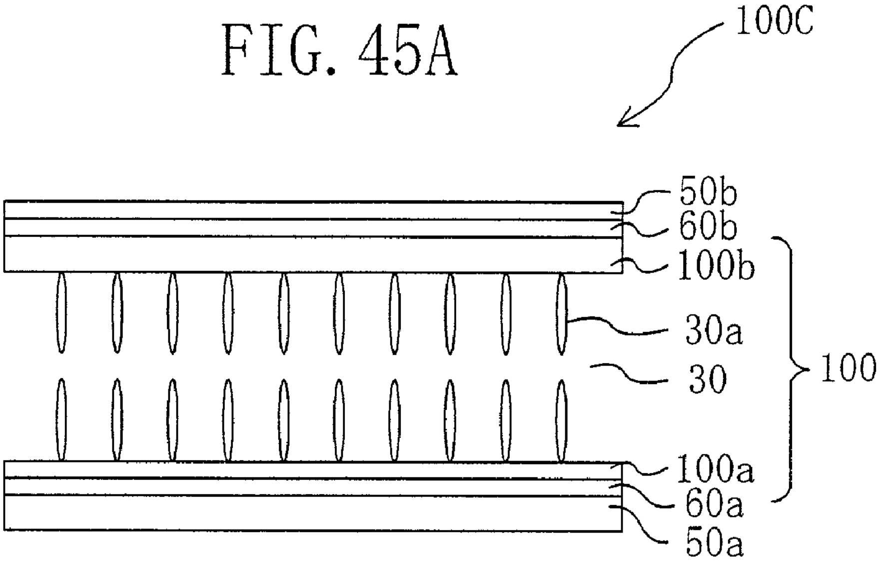


FIG. 45B

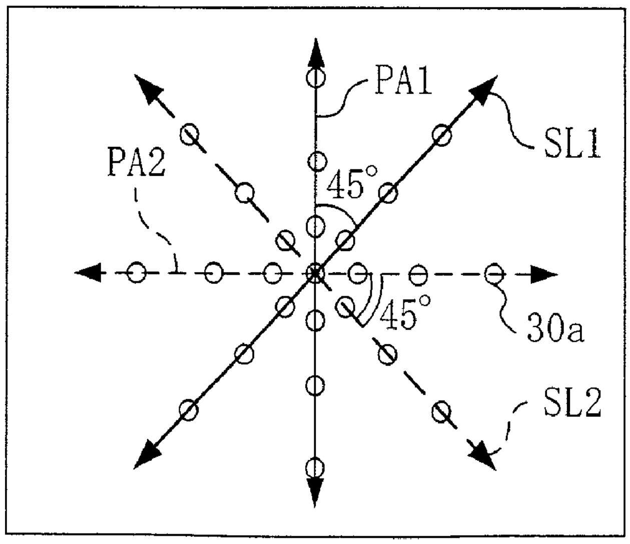


FIG. 46A

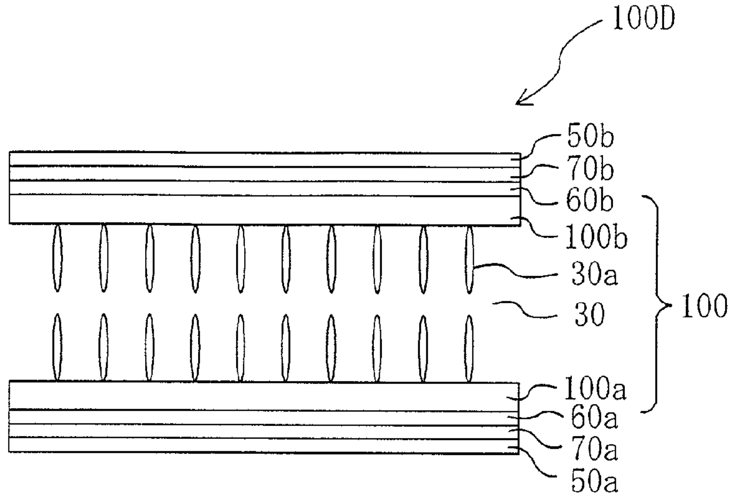


FIG. 46B

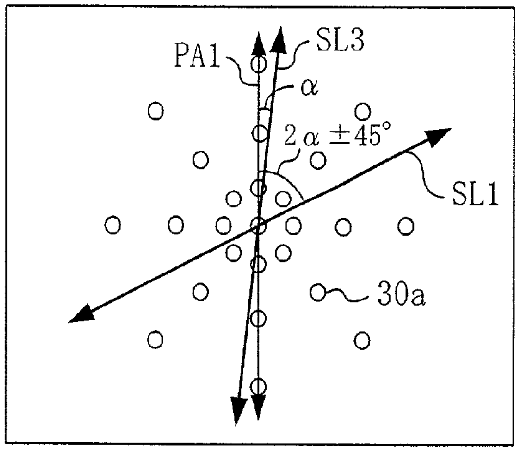


FIG. 46C

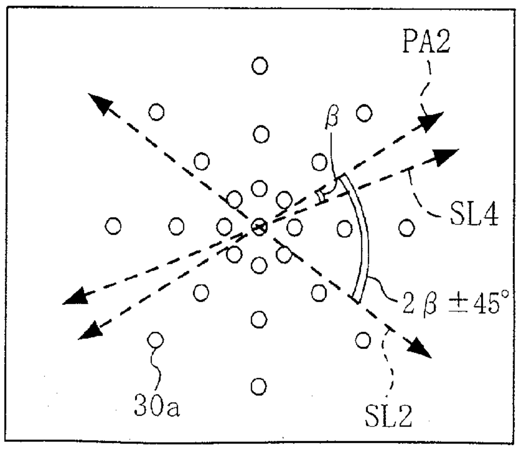


FIG. 47A

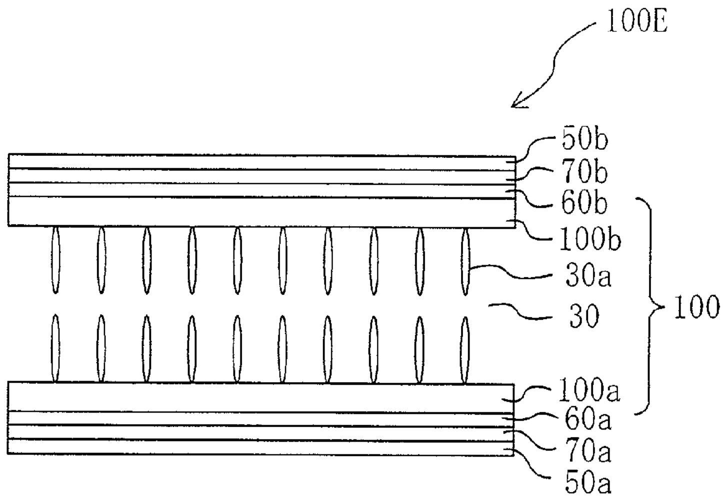


FIG. 47B

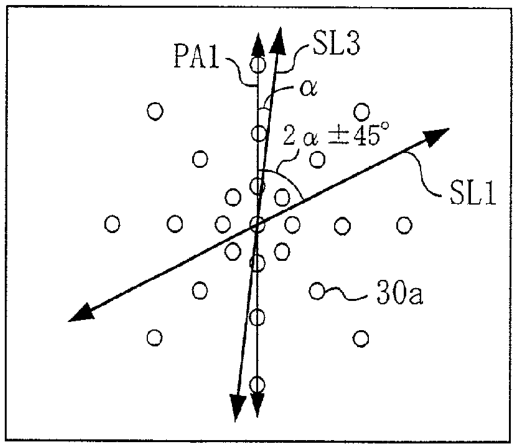


FIG. 47C

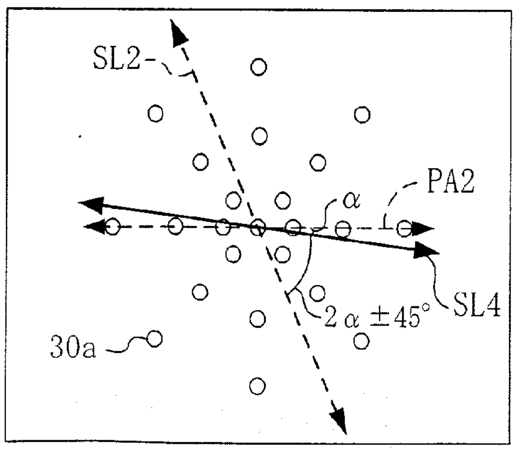


FIG. 48

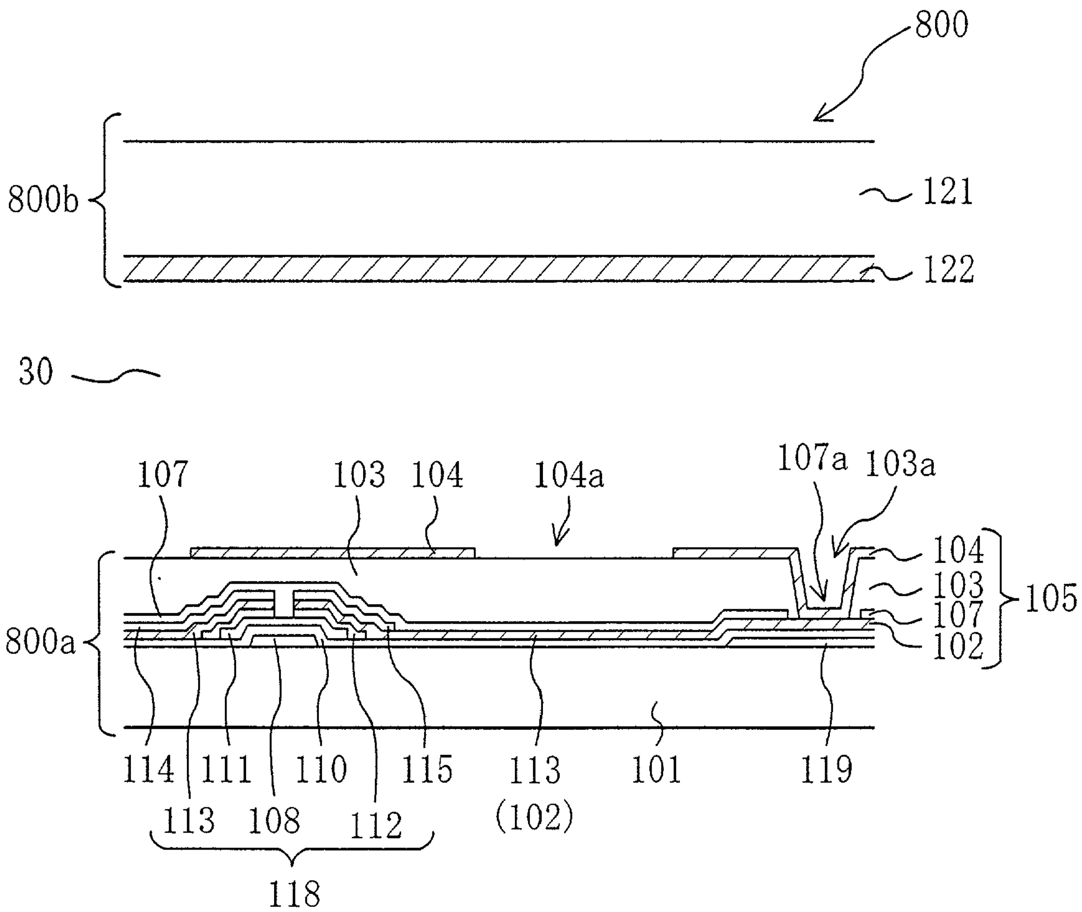

800
800b
121
122
30
107
103
104
104a
107a
103a
104
103
107
102
105
800a
114
111
110
115
113
101
119
113
108
112
(102)
118

FIG. 49

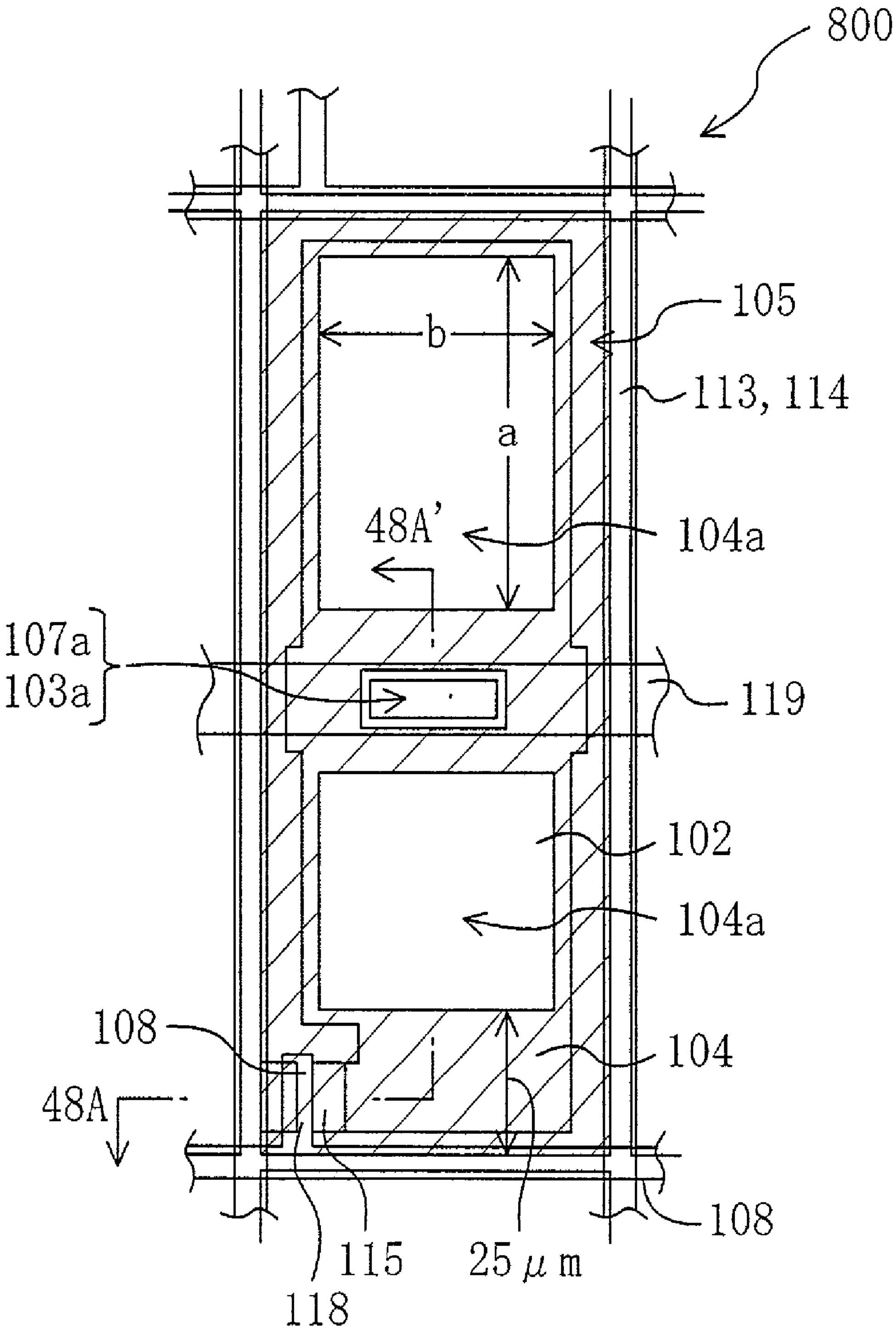

800
105
b
113, 114
a
48A'
104a
107a
103a
119
102
104a
108
104
48A
108
115
25 μm
118

FIG. 50A

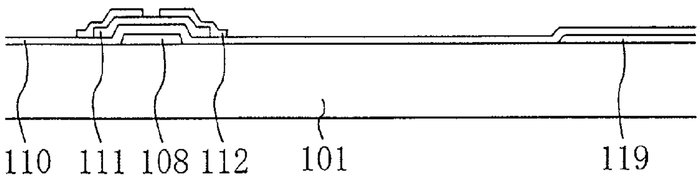


FIG. 50B

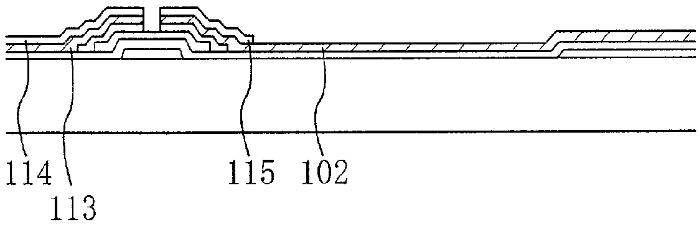


FIG. 50C

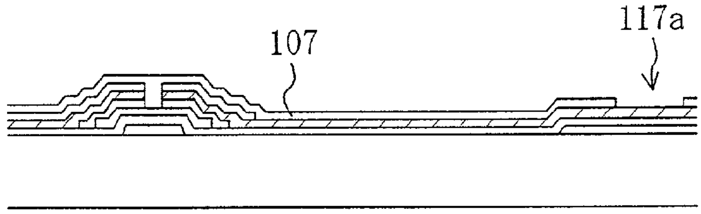


FIG. 50D

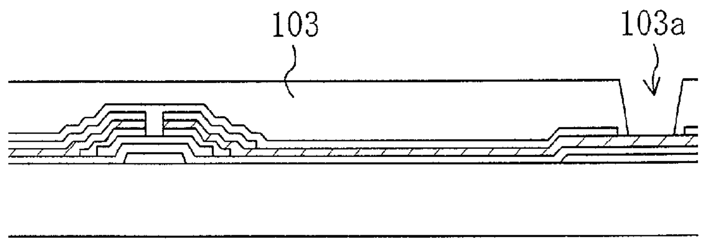


FIG. 50E

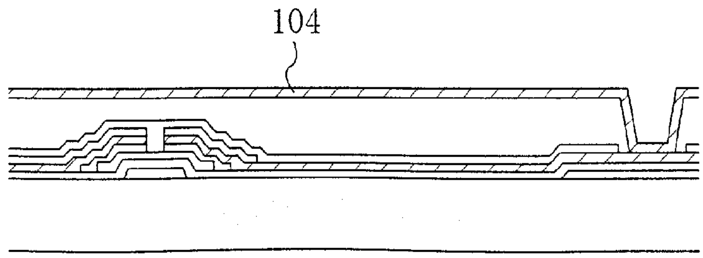


FIG. 50F

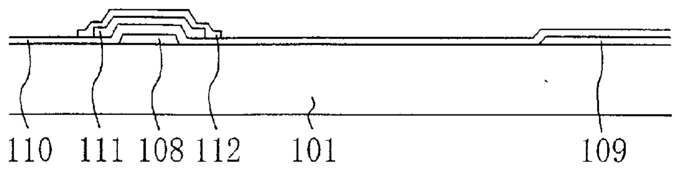


FIG. 50G

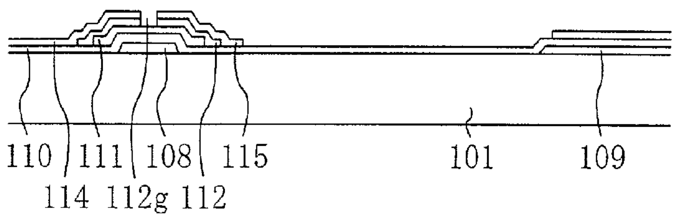


FIG. 50H

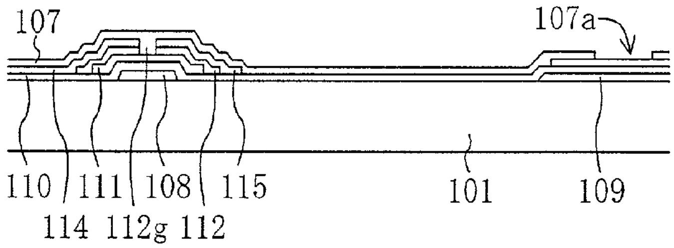


FIG. 50I

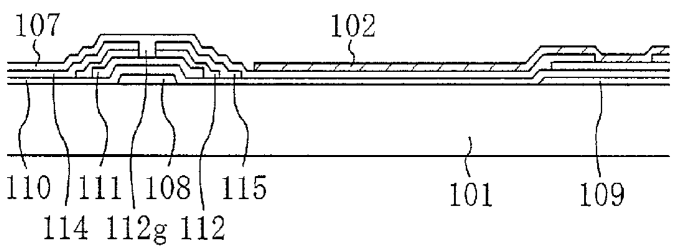


FIG. 50J

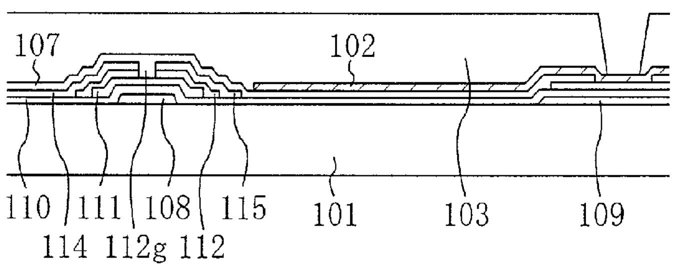


FIG. 50K

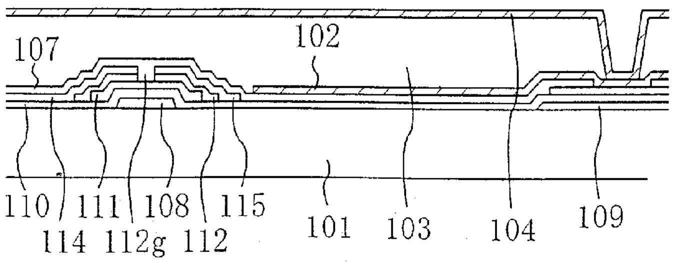


FIG. 51

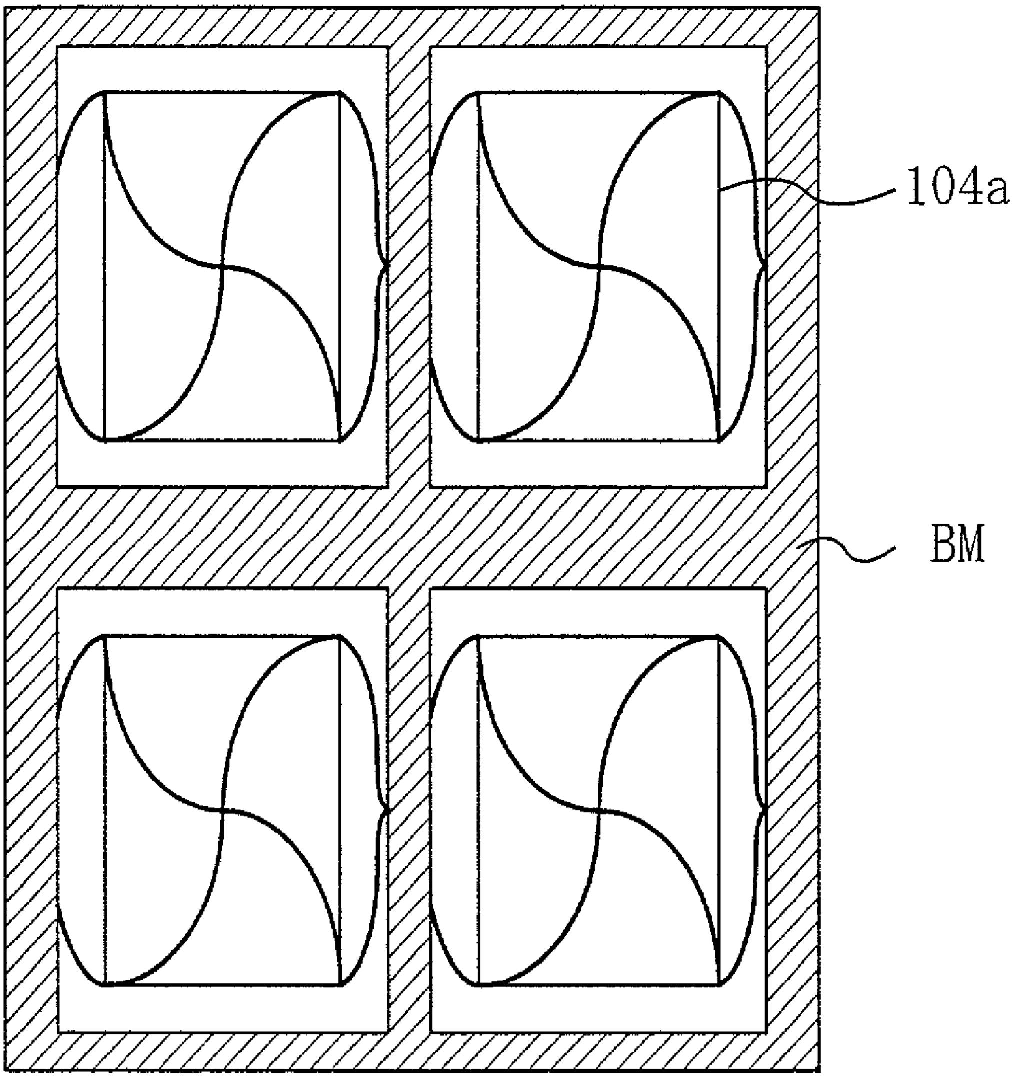


FIG. 52

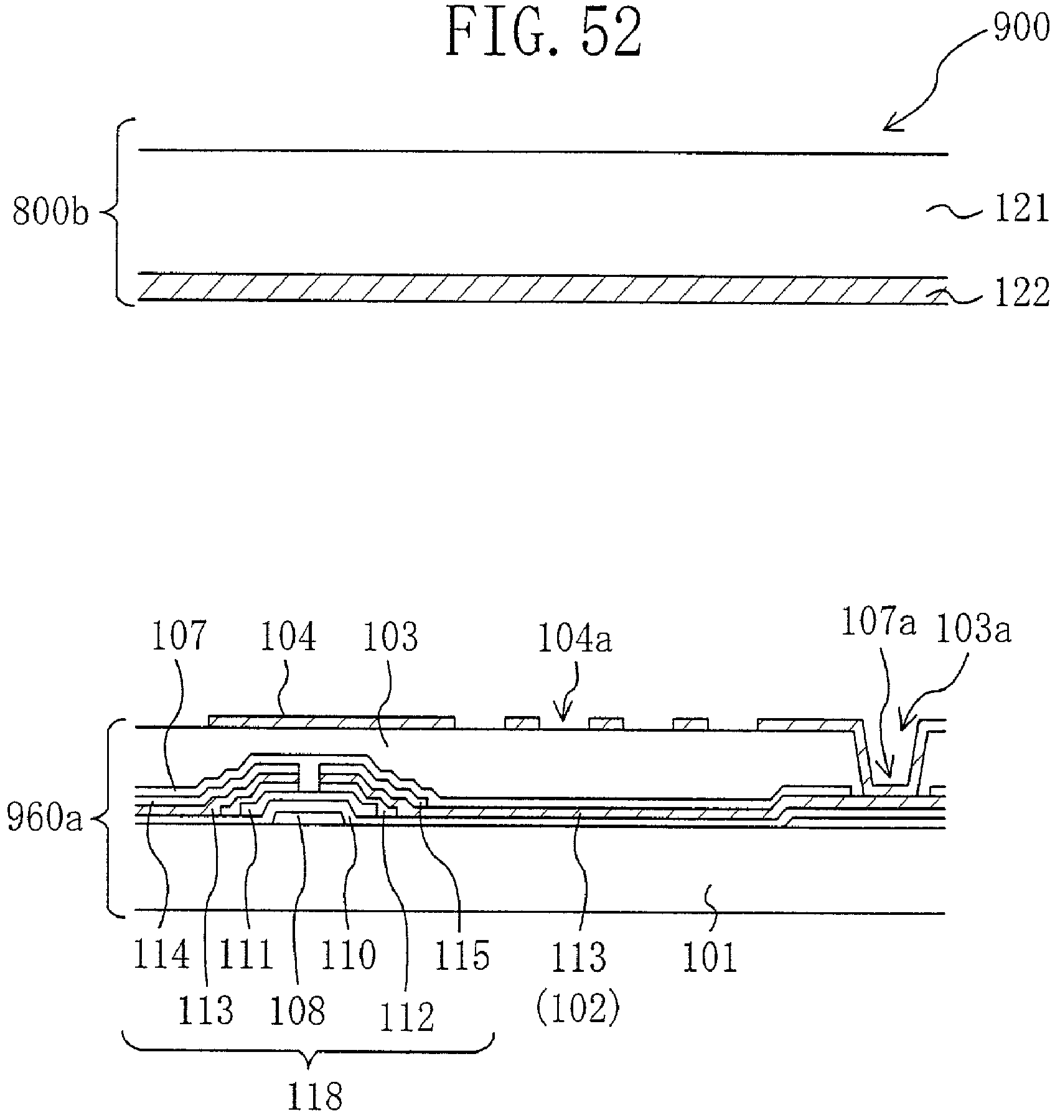

900
800b
121
122
107
104
103
104a
107a
103a
960a
114
111
110
115
113
(102)
101
113
108
112
118

FIG. 53

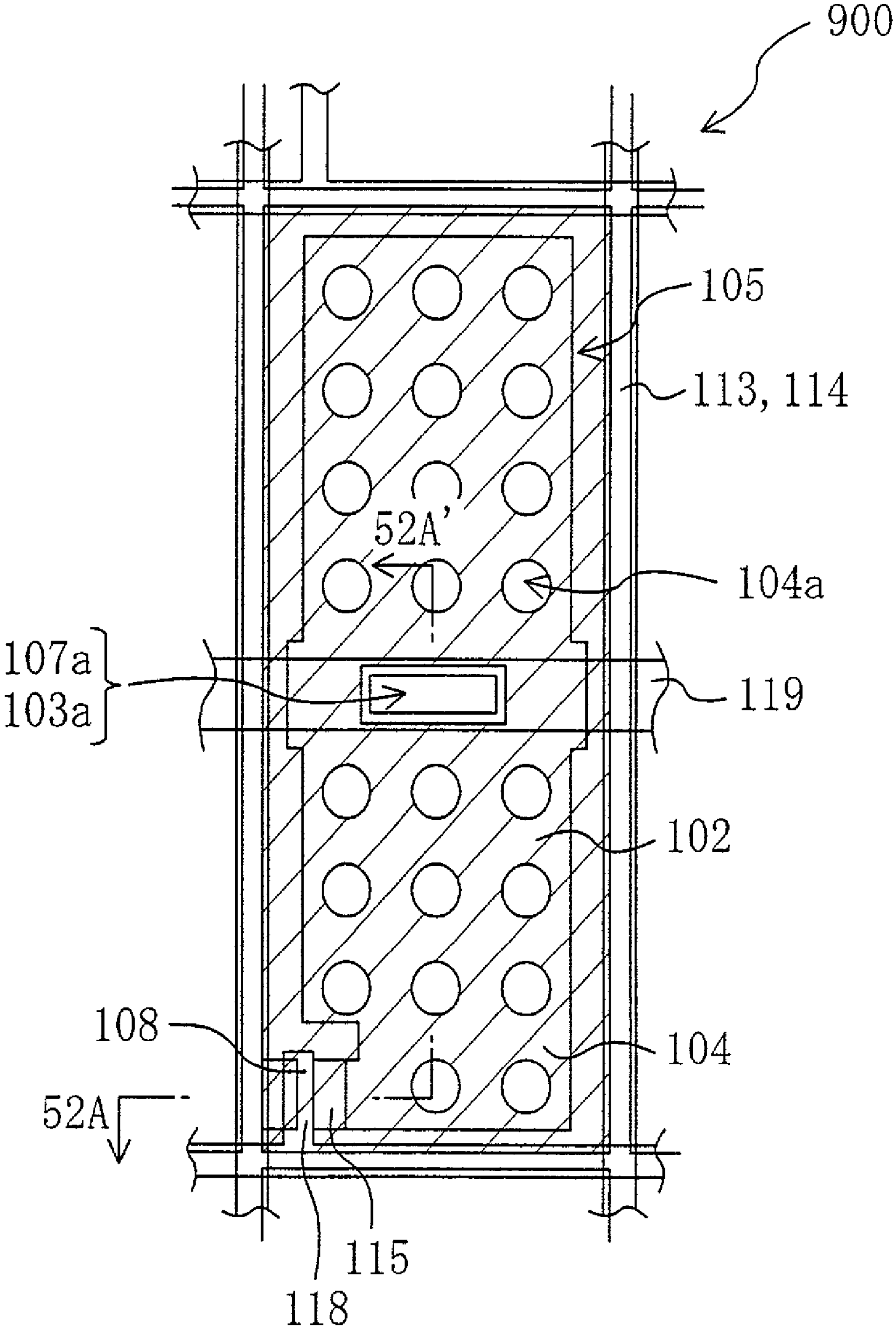


FIG. 54

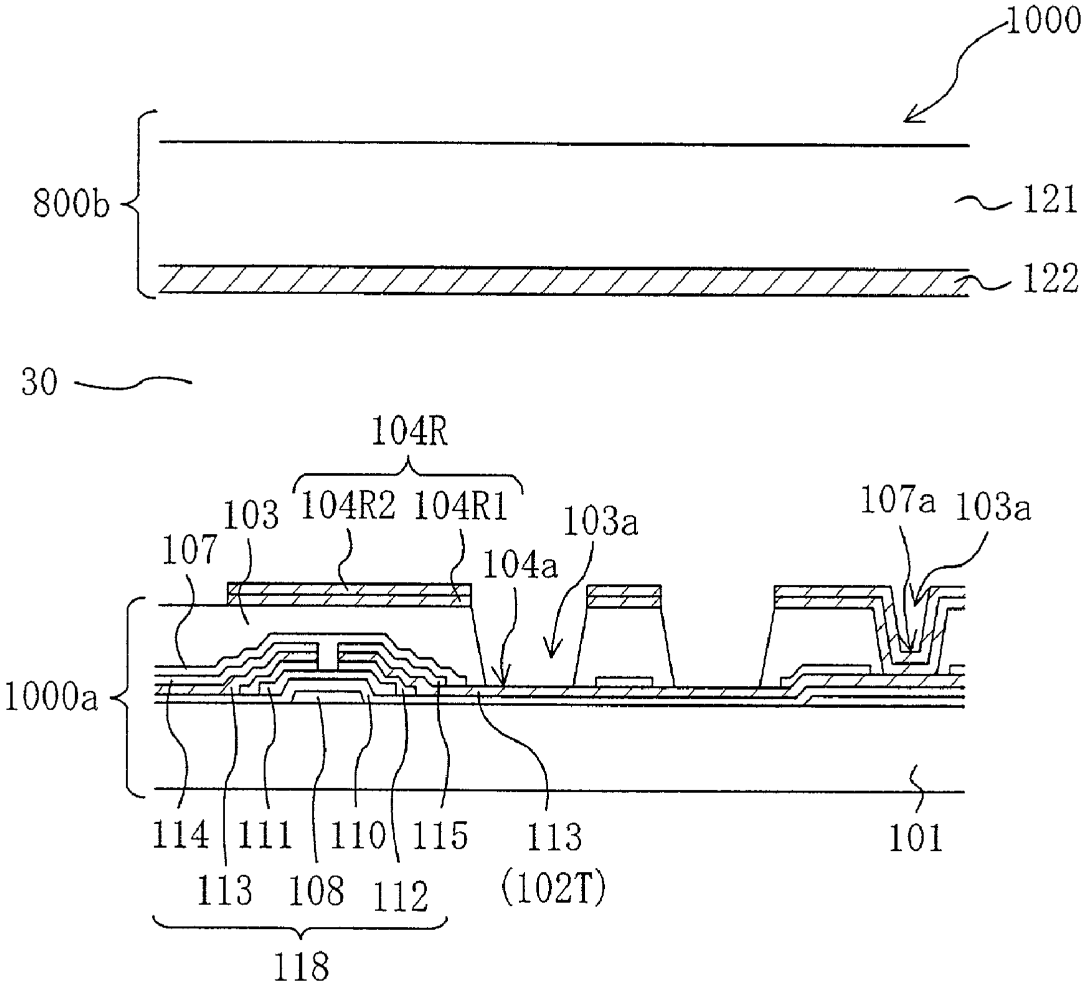

1000
800b
121
122
30
104R
104R2 104R1
103
107
104a
103a
107a 103a
1000a
114 111 110 115 113 101
113 108 112 (102T)
118

FIG. 55

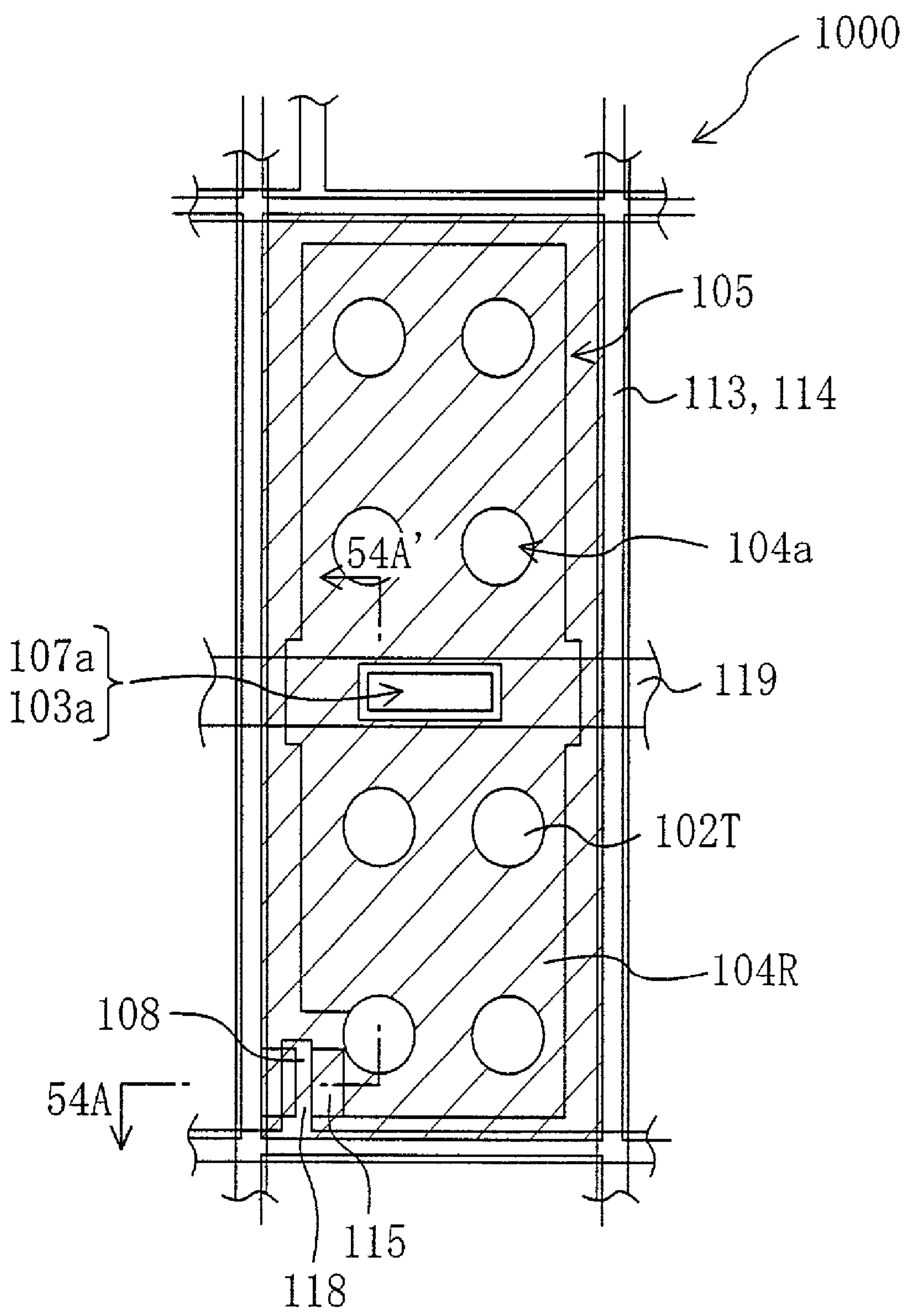

1000
105
113, 114
54A'
104a
107a
103a
119
102T
104R
108
54A
115
118

FIG. 56A

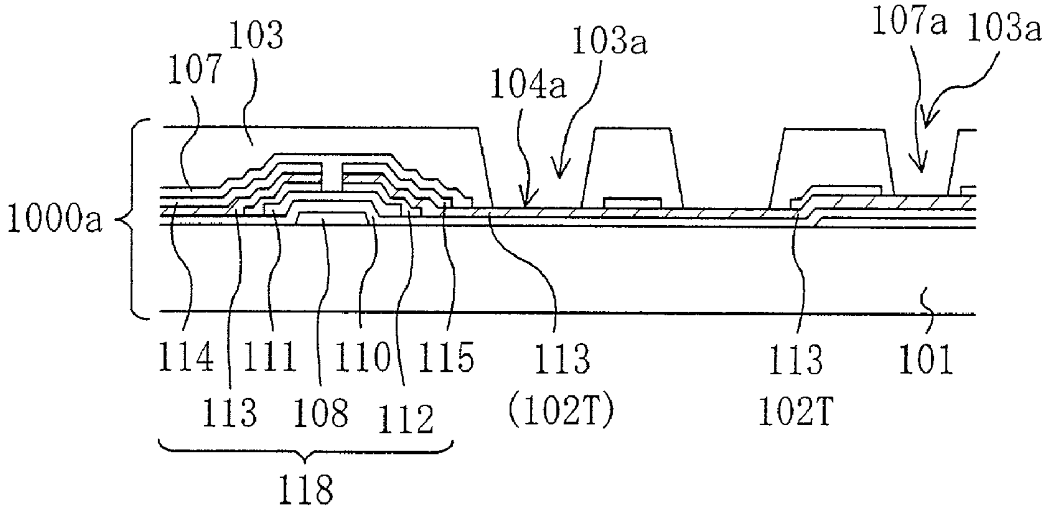


FIG. 56B

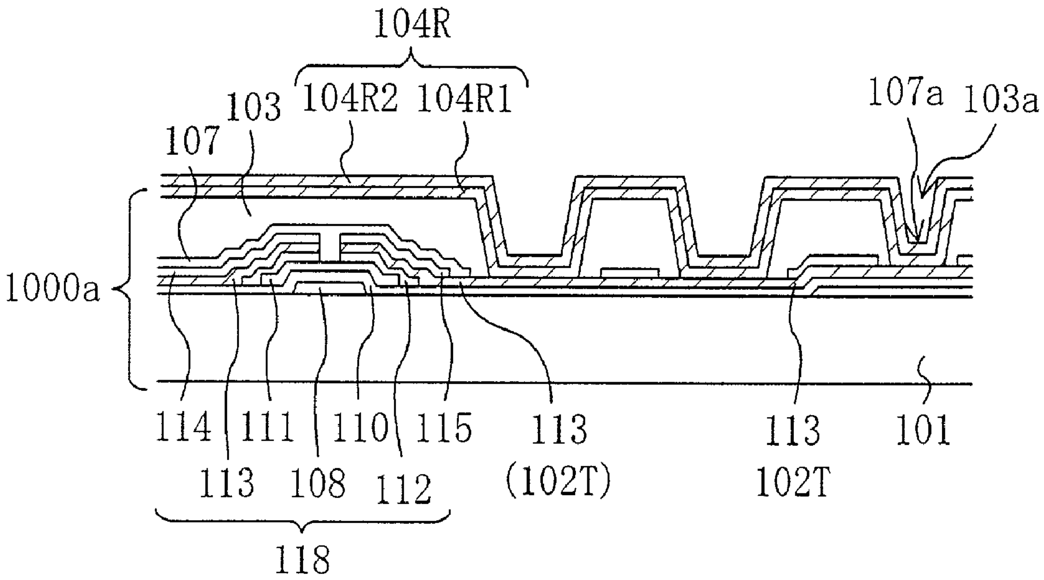


FIG. 57

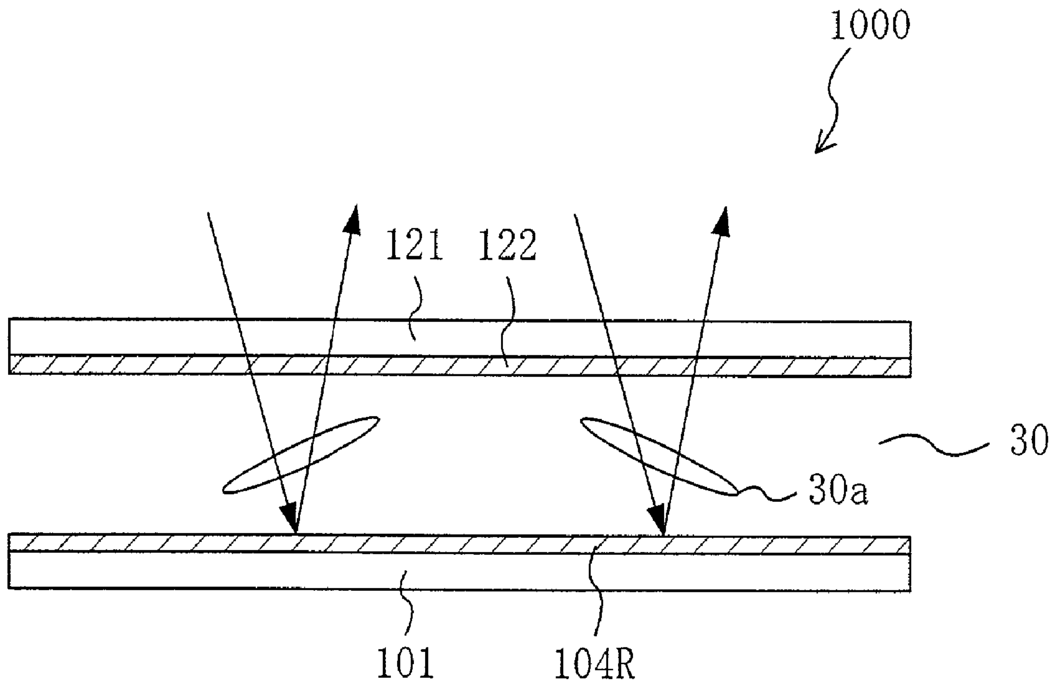


FIG. 58

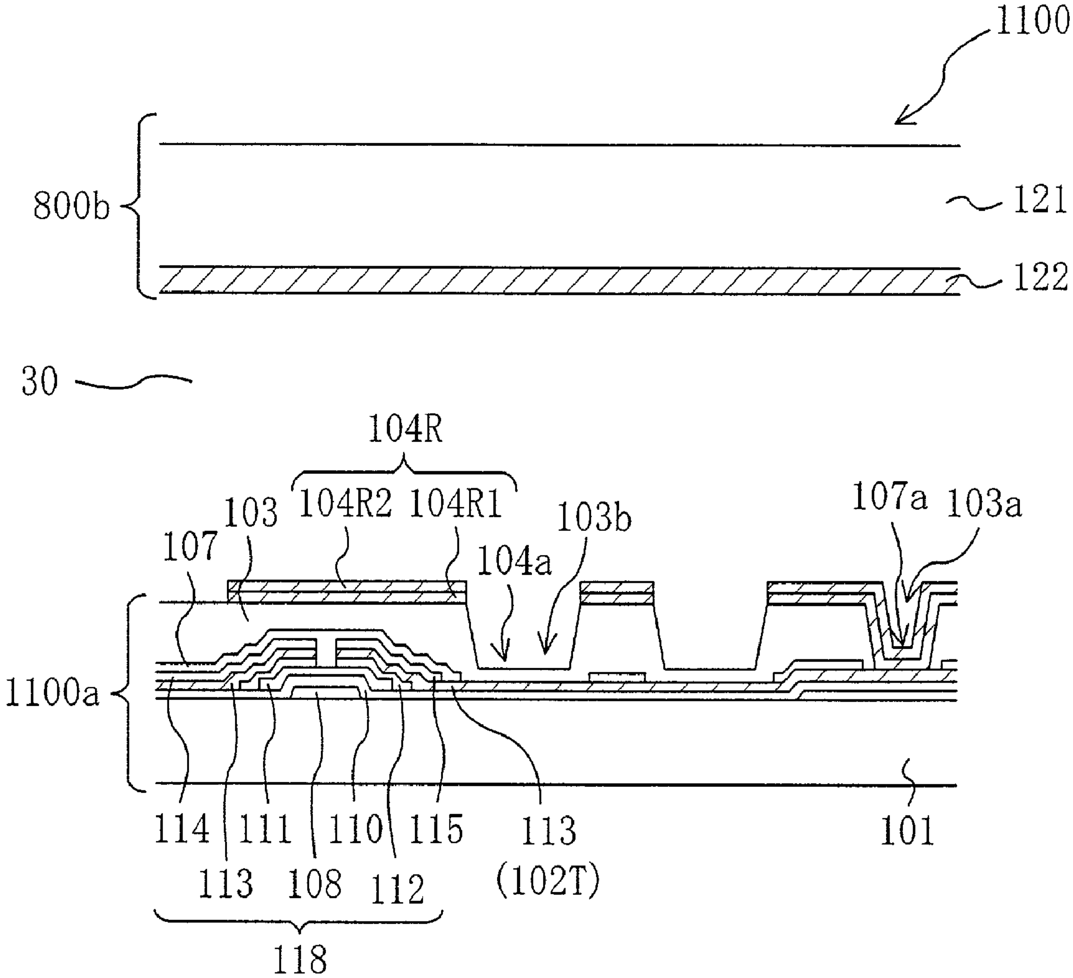

1100
800b
121
122
30
104R
104R2 104R1
103
107
103b
104a
107a 103a
1100a
114
111
110
115
113
(102T)
101
113
108
112
118

FIG. 59A

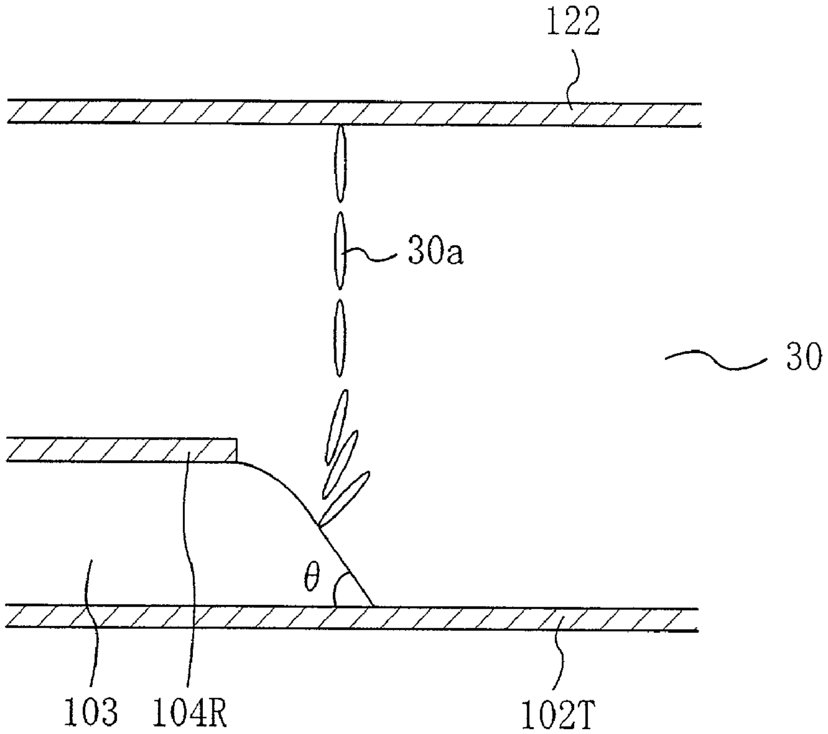


FIG. 59B

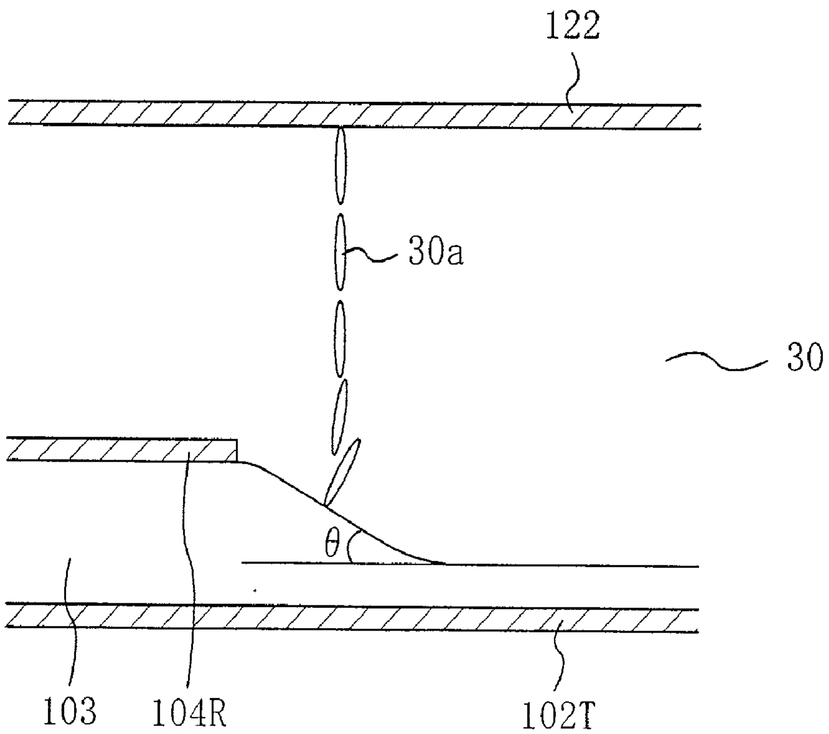


FIG. 60

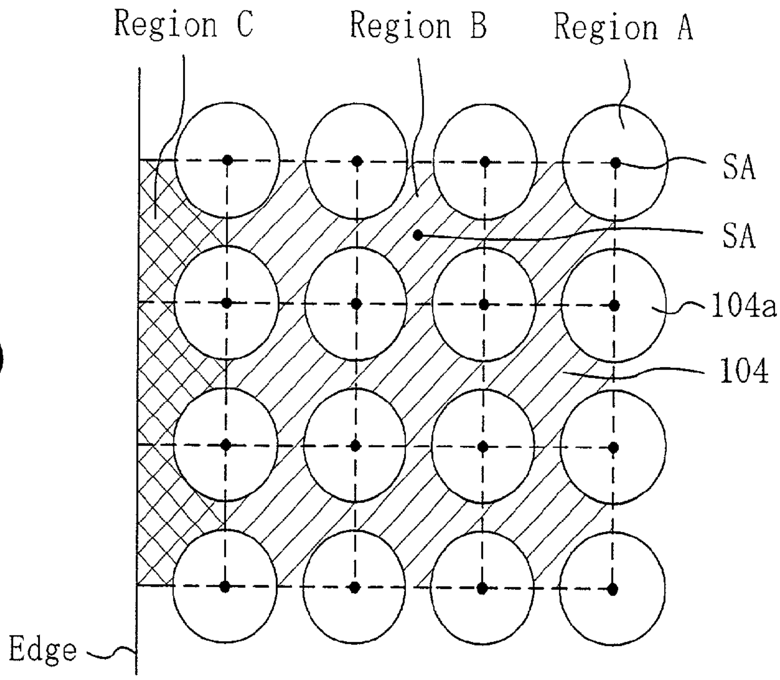

Region C
Region B
Region A
SA
SA
104a
104
Edge

FIG. 61

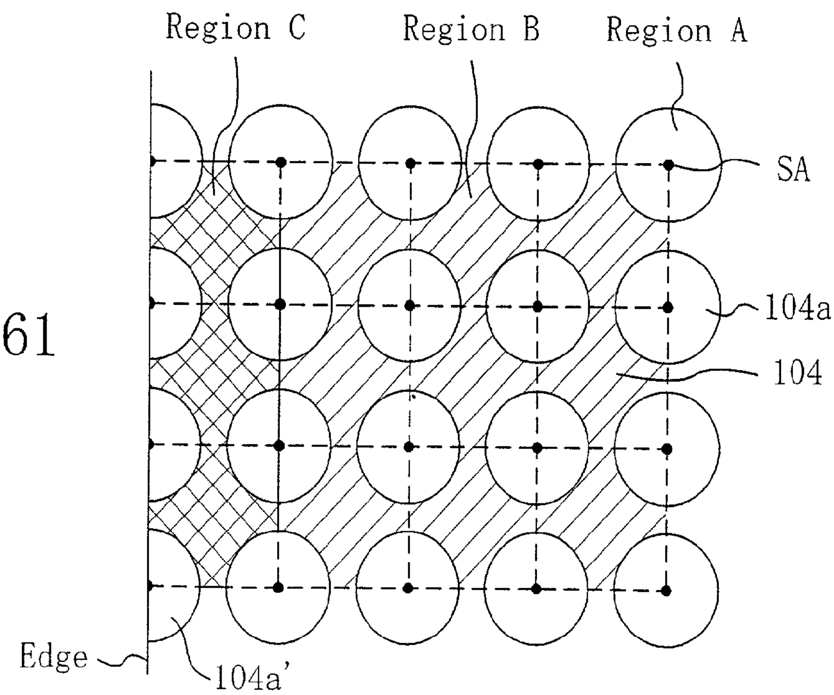

Region C
Region B
Region A
SA
104a
104
Edge
104a'

FIG. 62

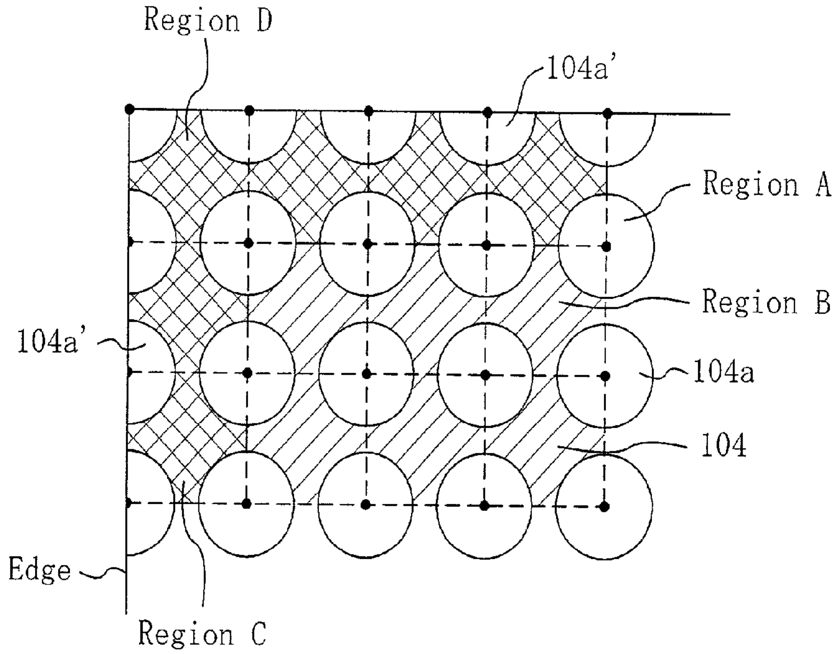

Region D
104a'
Region A
Region B
104a'
104a
104
Edge
Region C

FIG. 63

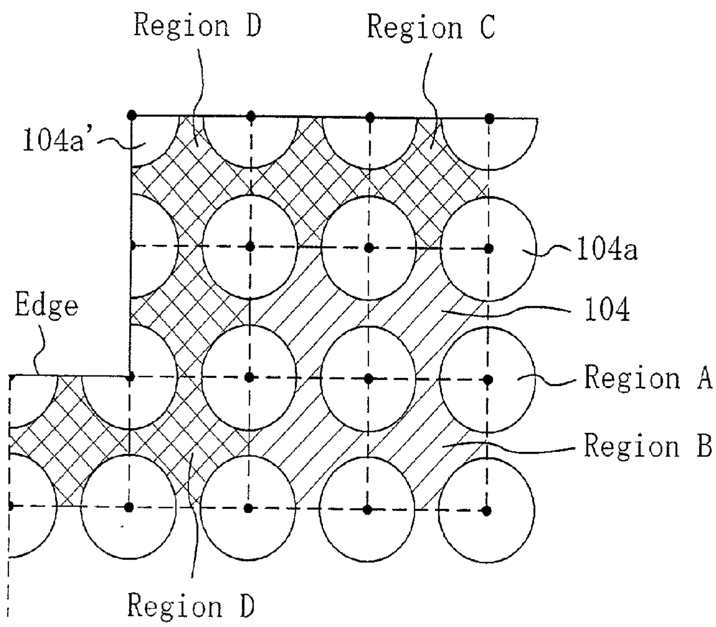

Region D
Region C
104a'
104a
Edge
104
Region A
Region B
Region D

FIG. 64

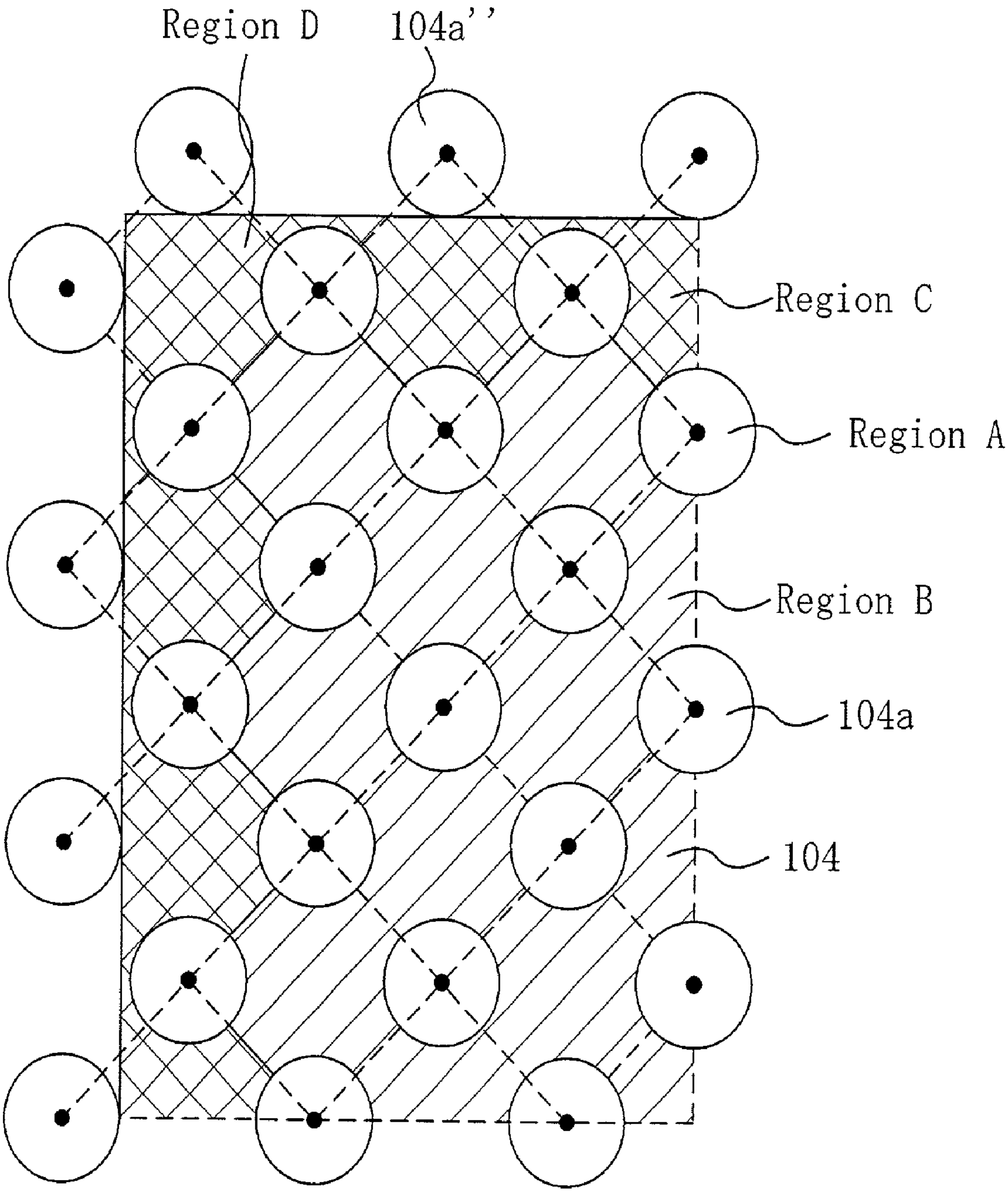


FIG. 65

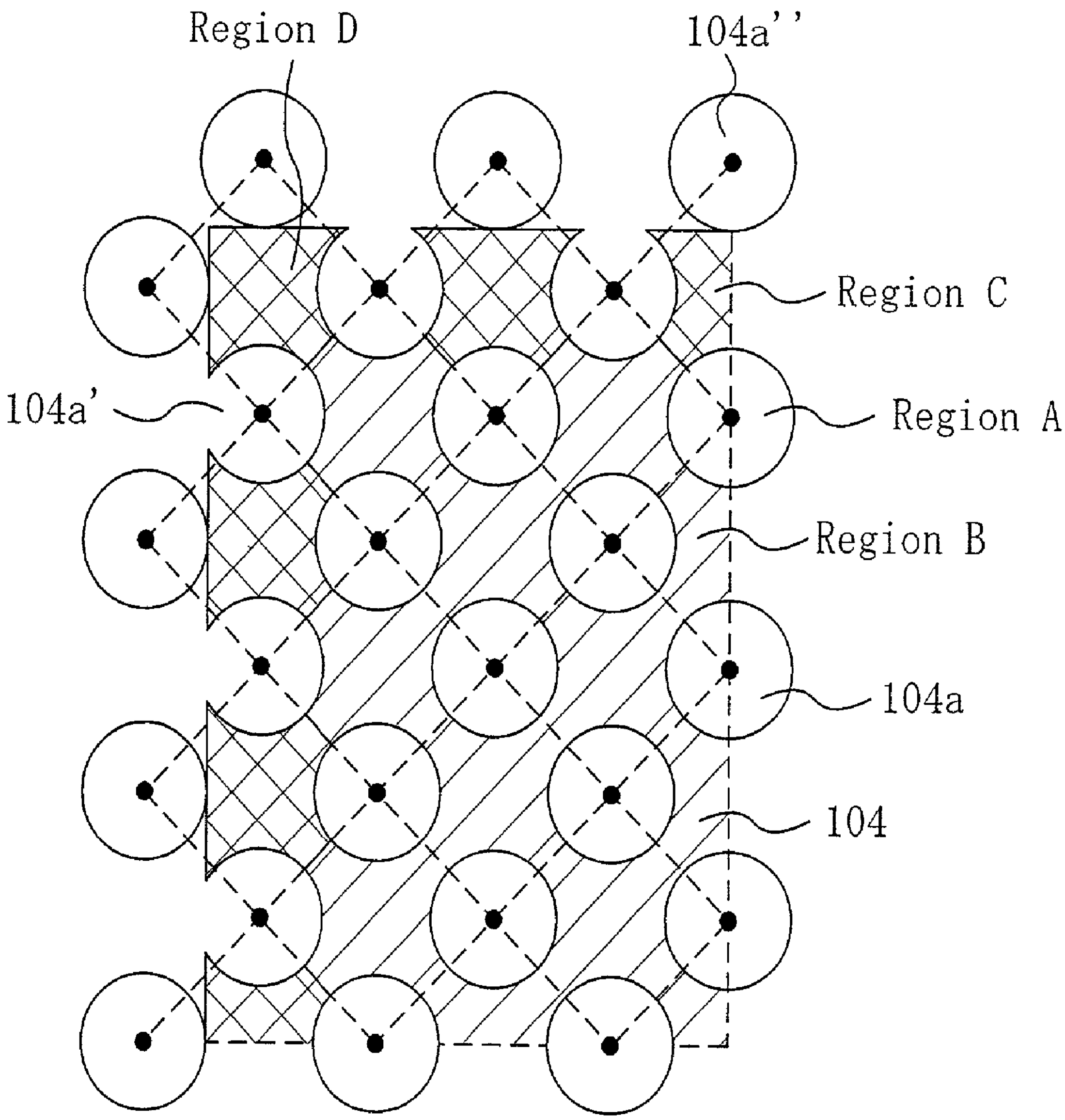


FIG. 66

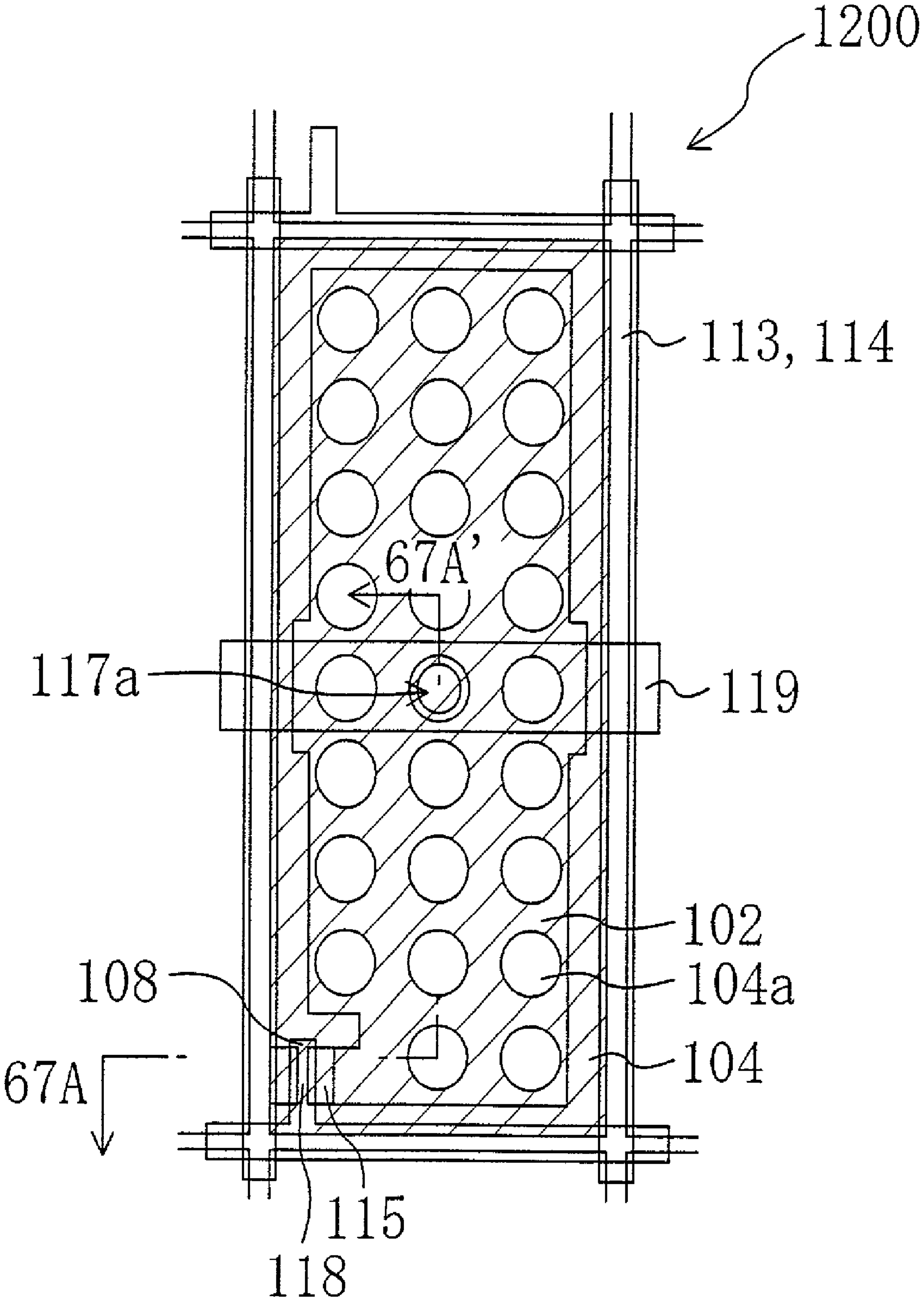


FIG. 67

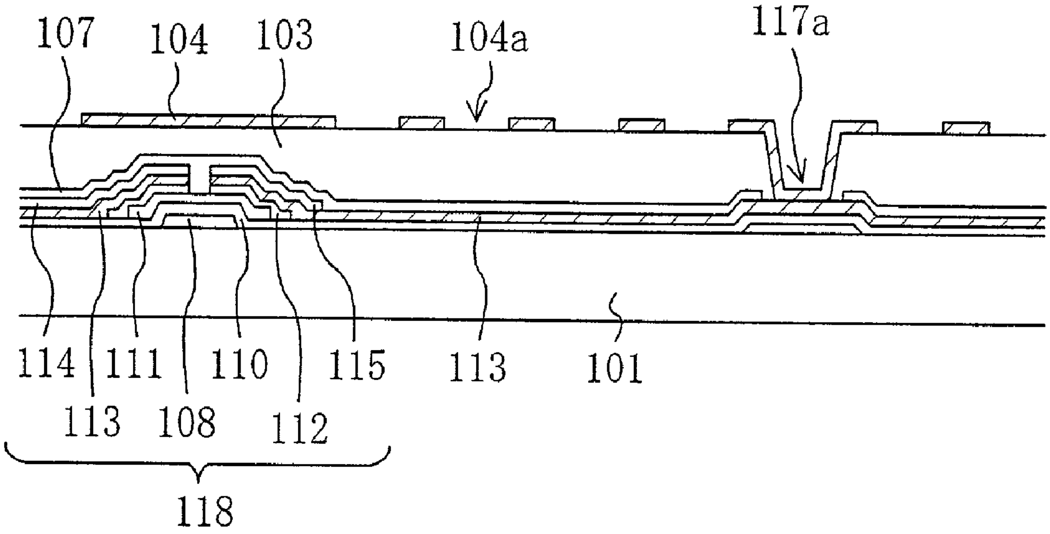


FIG. 68

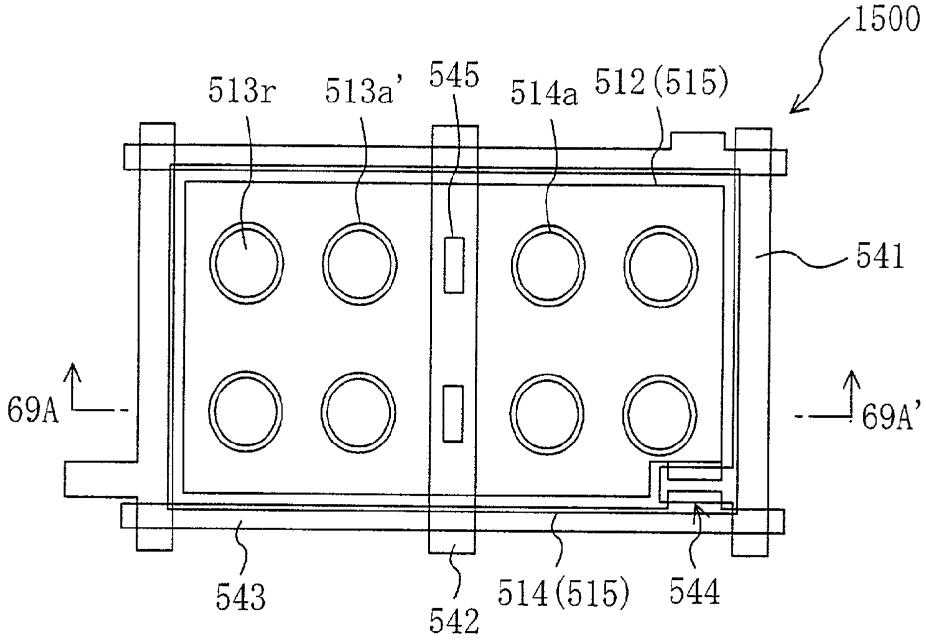

1500
513r
513a'
545
514a
512(515)
541
69A
69A'
543
542
514(515)
544

FIG. 69

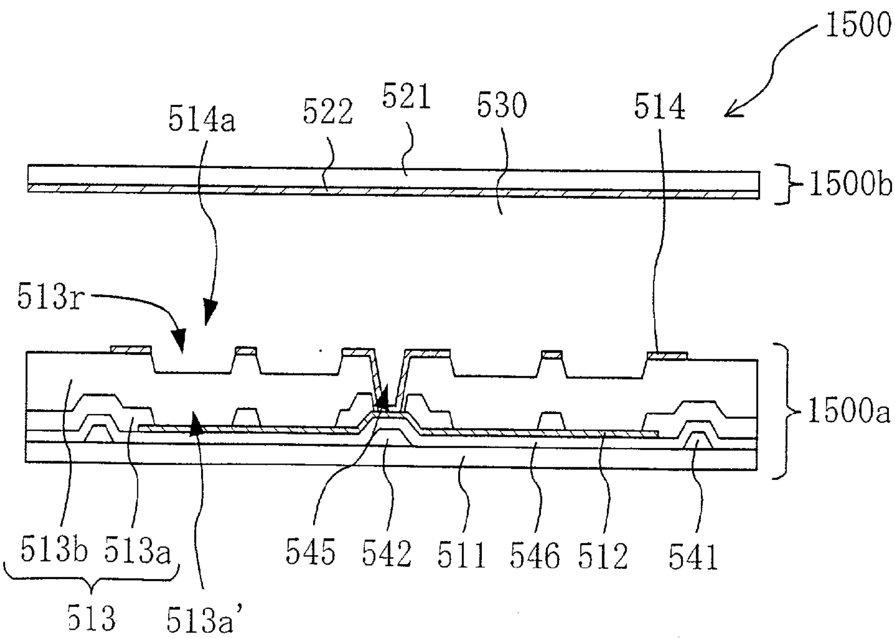

1500
514a
522
521
530
514
1500b
513r
1500a
513b
513a
513
513a'
545
542
511
546
512
541

FIG. 70

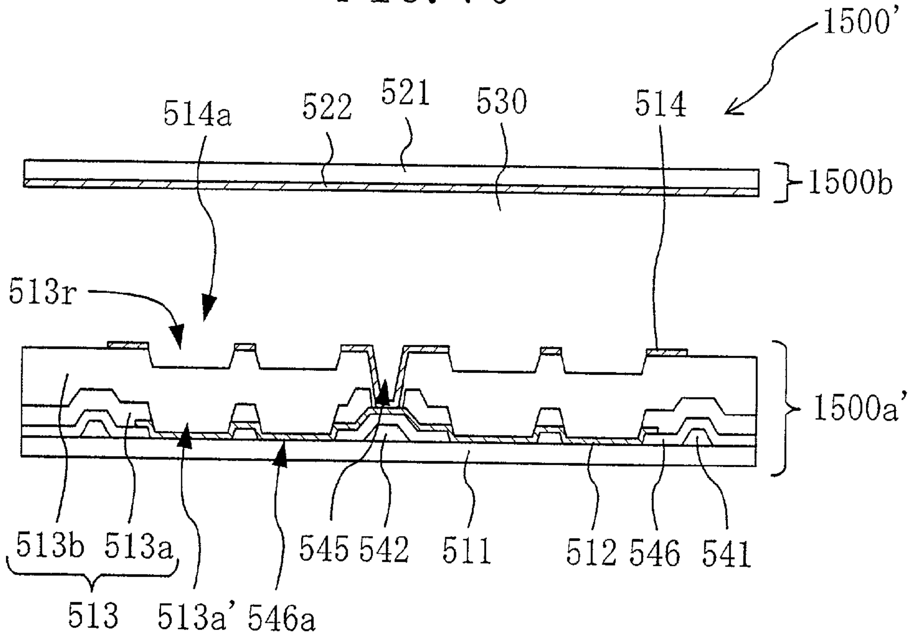

1500'
514a
522
521
530
514
1500b
513r
1500a'
513b 513a
513
513a' 546a
545 542
511
512 546 541

FIG. 71

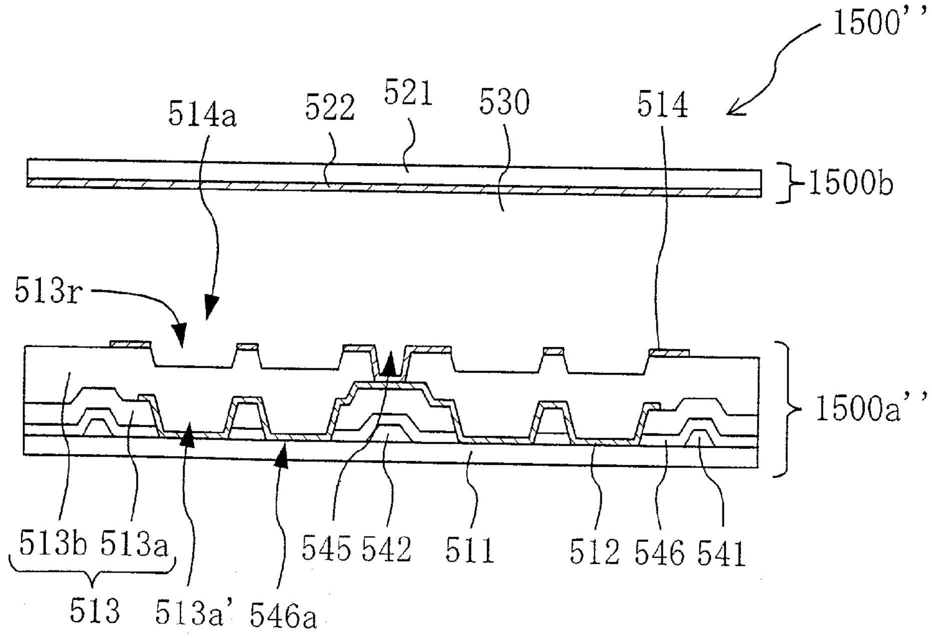

1500''
514a
522
521
530
514
1500b
513r
1500a''
513b 513a
513
513a' 546a
545 542
511
512 546 541

FIG. 72A

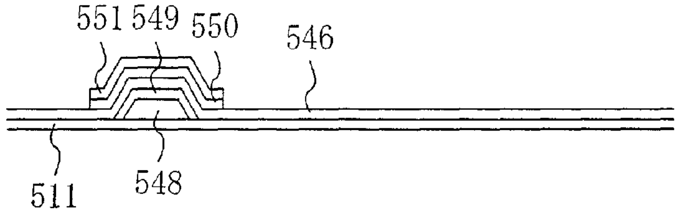


FIG. 72B

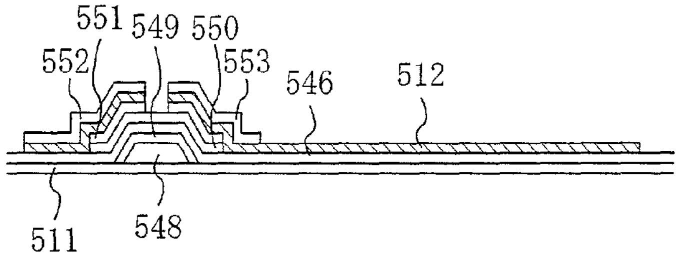


FIG. 72C

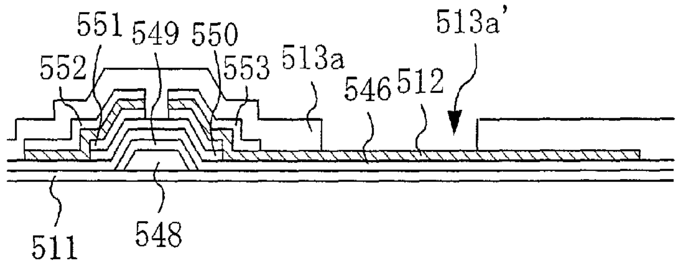


FIG. 72D

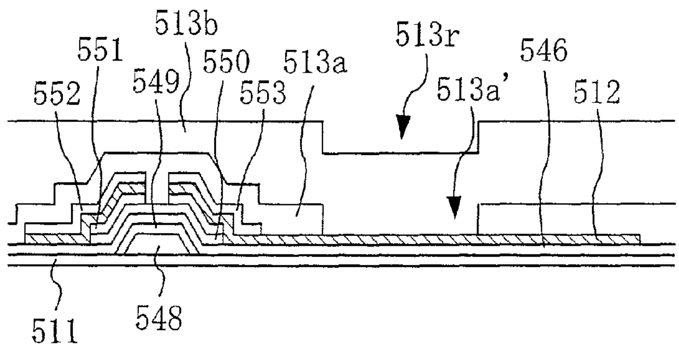


FIG. 72E

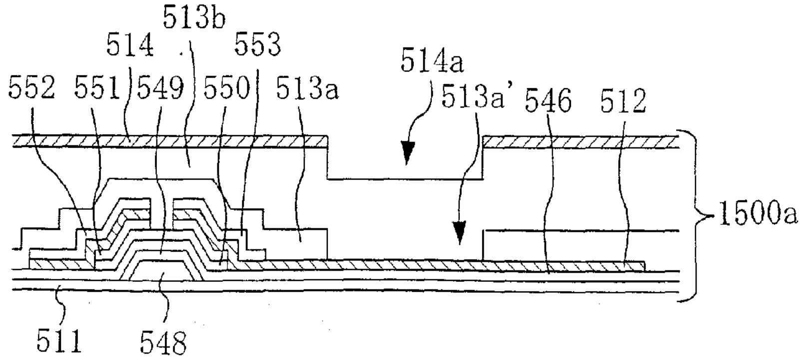


FIG. 73A

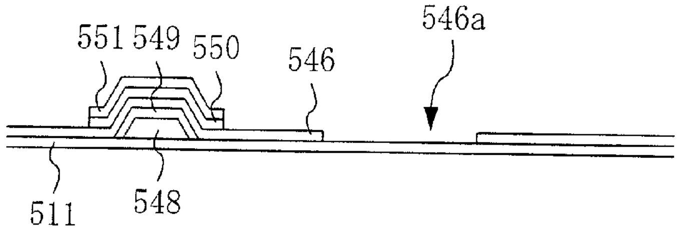


FIG. 73B

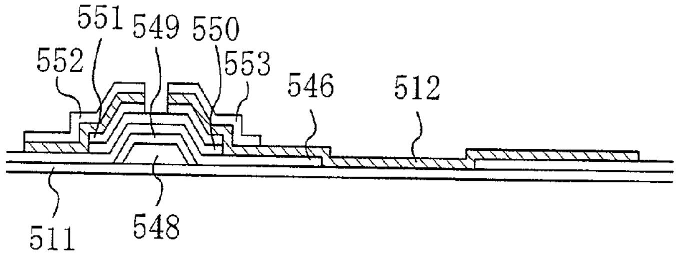


FIG. 73C

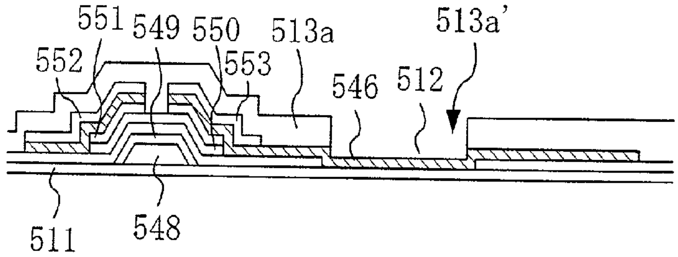


FIG. 73D

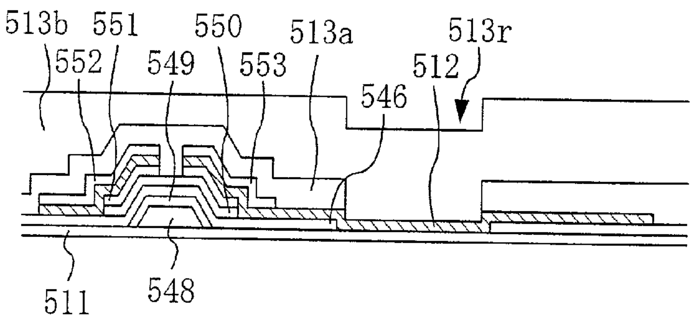
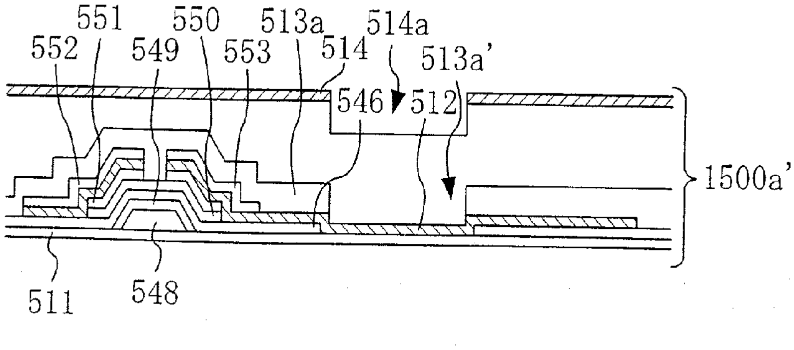


FIG. 73E



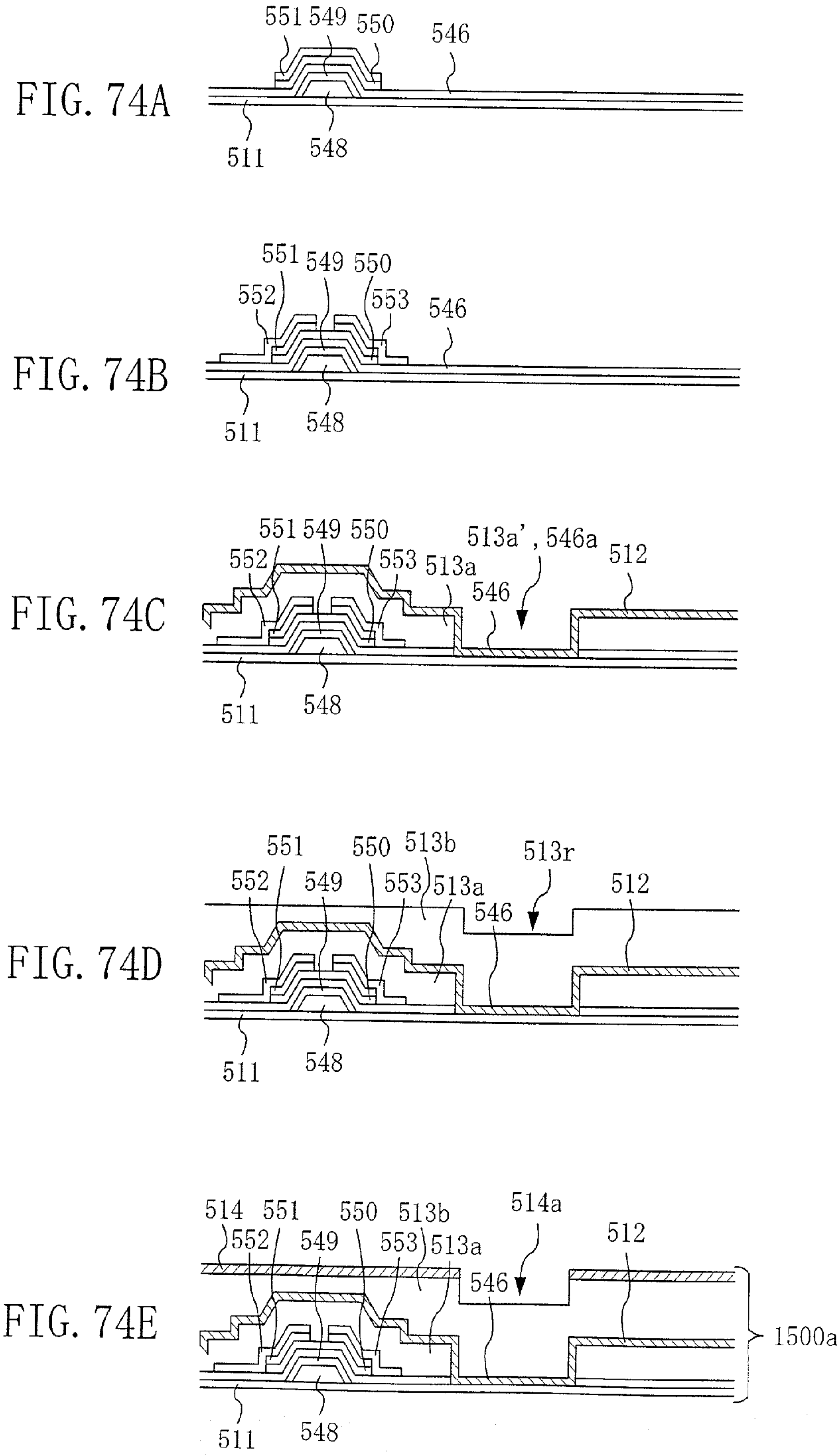


FIG. 74A
551 549 550
546
511
548
FIG. 74B
551 549 550
552
553
546
511
548
FIG. 74C
551 549 550
513a', 546a
512
552
553
513a
546
511
548
FIG. 74D
551
550 513b
513r
552
549
553
513a
512
546
511
548
FIG. 74E
514 551
550 513b
514a
552
549
553
513a
512
546
1500a
511
548

FIG. 75

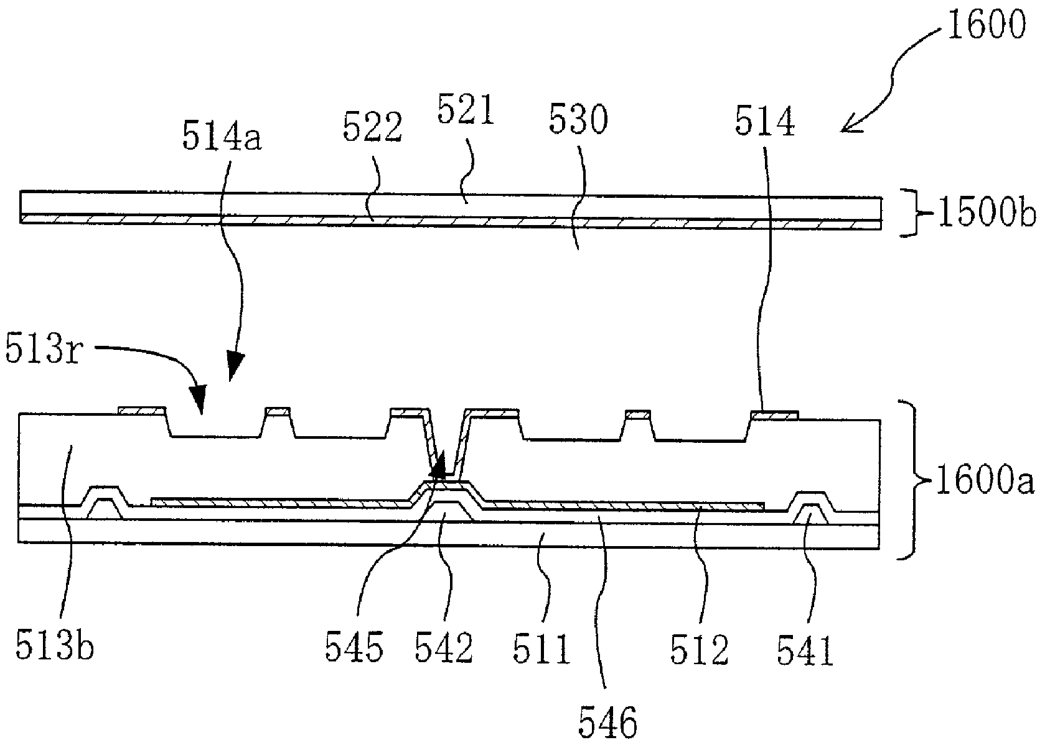

1600
514a
522
521
530
514
1500b
513r
1600a
513b
545
542
511
512
541
546

FIG. 76A

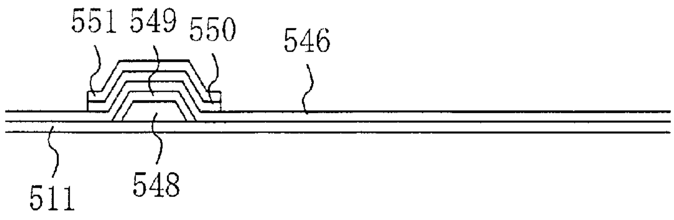


FIG. 76B

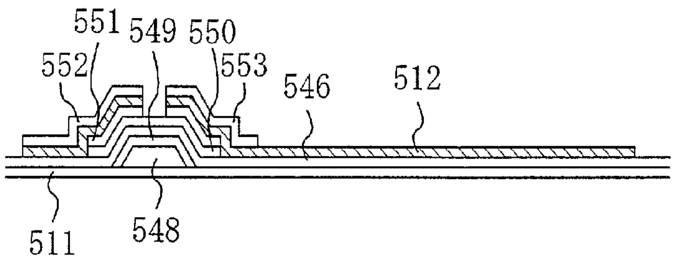


FIG. 76C

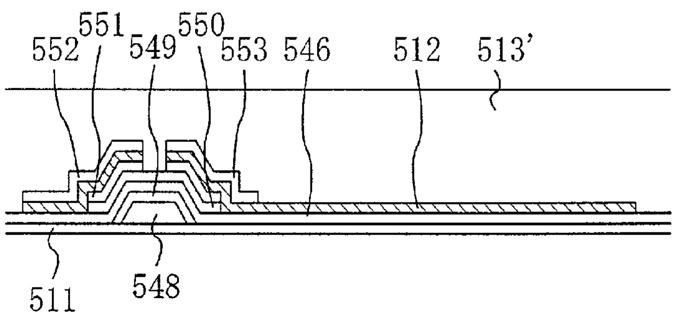


FIG. 76D

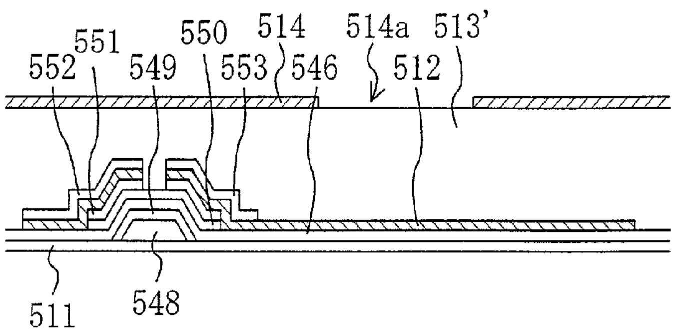
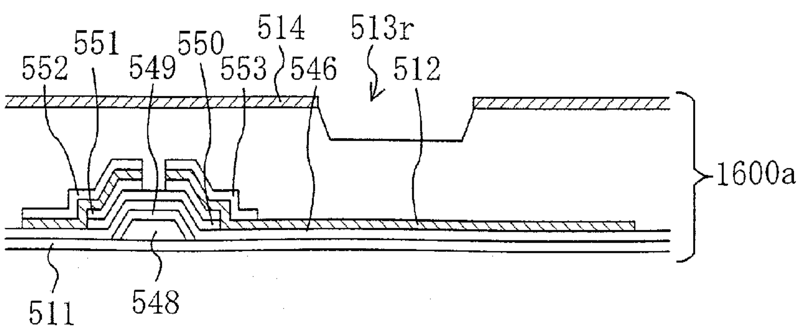


FIG. 76E



LIQUID CRYSTAL DISPLAY DEVICE

BACKGROUND OF THE INVENTION

[0001] The present invention relates to a liquid crystal display device. More specifically, the present invention relates to a liquid crystal display device having a wide viewing angle characteristic and capable of performing a high quality display.

[0002] In recent years, liquid crystal display devices, which are thin and light in weight, are used for personal computers and PDA (personal digital assistance) devices. However, conventional twist nematic (TN) type and super twist nematic (STN) type liquid crystal display devices have a narrow viewing angle. Various technical developments have been undertaken to solve the problem.

[0003] A typical technique for improving the viewing angle characteristic of a TN or STN type liquid crystal display device is to add an optical compensation plate thereto. Another approach is to employ a transverse electric field mode in which a horizontal electric field with respect to the substrate plane is applied across the liquid crystal layer. Transverse electric field mode liquid crystal display devices have been attracting public attention and are mass-produced in recent years. Still another technique is to employ a DAP (deformation of vertical aligned phase) mode in which a nematic liquid crystal material having a negative dielectric anisotropy is used as a liquid crystal material and a vertical alignment film is used as an alignment film. This is a type of ECB (electrically controlled birefringence) mode, in which the transmittance is controlled by using the birefringence of liquid crystal molecules.

[0004] While the transverse electric field mode is an effective approach to improve the viewing angle, the production process thereof imposes a significantly lower production margin than that of a normal TN type device, whereby it is difficult to realize stable production of the device. This is because the display brightness or the contrast ratio is significantly influenced by variations in the gap between the substrates or a shift in the direction of the transmission axis (polarization axis) of a polarizing plate (polarizer) with respect to the orientation axis of the liquid crystal molecules. It requires further technical developments to be able to precisely control these factors and thus to realize stable production of the device.

[0005] In order to realize a uniform display without display non-uniformity with a DAP mode liquid crystal display device, an alignment control is necessary. An alignment control can be provided by, for example, subjecting the surface of an alignment film to an alignment treatment by rubbing. However, when a vertical alignment film is subjected to a rubbing treatment, rubbing streaks are likely to appear in the displayed image, and it is not suitable for mass-production.

[0006] Another approach proposed in the art for performing an alignment control without a rubbing treatment is to form a slit (opening) in an electrode so as to produce an inclined electric field and to control the orientation direction of the liquid crystal molecules by the inclined electric field (e.g., Japanese Laid-Open Patent Publication No. 6-301036). However, a study by the present inventors has shown that this approach has the following problems.

[0007] With a slit (opening) in an electrode for producing an inclined electric field, a sufficient voltage cannot be applied across the liquid crystal layer in regions corresponding to the slits in the electrode, whereby the orientation of the liquid crystal molecules of the liquid crystal layer in the regions corresponding to the slits cannot be sufficiently controlled, thereby resulting in loss of transmittance in the presence of an applied voltage.

SUMMARY OF THE INVENTION

[0008] In view of the above-mentioned conventional problems, the present invention has been devised for the purpose of realizing a liquid crystal display device having a high display quality and a method for producing the same.

[0009] A liquid crystal display device of the present invention includes: a first substrate, a second substrate, and a liquid crystal layer provided between the first substrate and the second substrate; and a plurality of picture element regions each defined by a first electrode provided on one side of the first substrate which is closer to the liquid crystal layer and a second electrode provided on the second substrate so as to oppose the first electrode via the liquid crystal layer, wherein: the liquid crystal layer in each of the plurality of picture element regions takes a vertical alignment in the absence of an applied voltage between the first electrode and the second electrode, and changes its orientation according to a voltage applied between the first electrode and the second electrode; the first electrode includes a lower conductive layer, a dielectric layer covering at least a portion of the lower conductive layer, and an upper conductive layer provided on one side of the dielectric layer which is closer to the liquid crystal layer; and the upper conductive layer includes at least one first opening, and the lower conductive layer is provided so as to oppose at least a portion of the at least one first opening via the dielectric layer. Thus, the above-described object is achieved. The upper conductive layer including the first opening functions to produce an inclined electric field at the edge portion of the first opening so as to orient the liquid crystal molecules into a radially-inclined orientation (or radially-inclined alignment). Since an electric field from the lower conductive layer is applied to a region opposing the first opening, the orientation of the liquid crystal molecules located above the first opening is stabilized.

[0010] Preferably, the lower conductive layer is provided in a region including a region opposing the at least one first opening via the dielectric layer. Thus, the electric field can effectively act upon the liquid crystal layer above the first opening.

[0011] The at least one first opening may have a square shape or a circular shape.

[0012] Preferably, the at least one first opening of the upper conductive layer includes a plurality of first openings. With a structure having a plurality of first opening, it is possible to achieve a stable radially-inclined orientation across the entire picture element region. Moreover, it is possible to suppress the decrease in the response speed.

[0013] Preferably, the plurality of first openings of the upper conductive layer are regularly arranged. Particularly, it is preferred that the plurality of first openings are arranged so as to have rotational symmetry.

[0014] The dielectric layer may include a depressed portion or an opening in the at least one first opening. With a structure where the dielectric layer includes a depressed portion or an opening, it is possible to suppress the voltage drop due to the dielectric layer. Moreover, it is possible to adjust the thickness of the liquid crystal layer.

[0015] The lower conductive layer may include a second opening in a region opposing the first opening. The second opening functions to stabilize the center of the radially-inclined orientation of the liquid crystal layer in the first opening.

[0016] One of the upper conductive layer and the lower conductive layer may be a transparent conductive layer, with the other one of the upper conductive layer and the lower conductive layer being a reflective conductive layer. Particularly, with a structure where the upper conductive layer is a reflective electrode and the lower conductive layer is a transparent electrode, it is possible to optimize each of the display characteristics in the transmission mode and the display characteristics in the reflection mode.

[0017] Preferably, the at least one first opening of the upper conductive layer includes a plurality of first opening; and a plurality of liquid crystal domains are formed in response to a voltage applied between the first electrode and the second electrode, each of the plurality of liquid crystal domains being formed in the liquid crystal layer corresponding to respective one of the first openings provided in the first electrode, and having a radially-inclined orientation.

[0018] The second substrate may further include an orientation-regulating structure in a region corresponding to at least one of the plurality of liquid crystal domains, the orientation-regulating structure exerting an orientation-regulating force for orienting liquid crystal molecules in the at least one liquid crystal domain into a radially-inclined orientation at least in the presence of an applied voltage.

[0019] Preferably, the orientation-regulating structure is provided in a region corresponding to a region in the vicinity of a center of the at least one liquid crystal domain.

[0020] Preferably, in the at least one liquid crystal domain, a direction of orientation regulation by the orientation-regulating structure coincides with a direction of the radially-inclined orientation.

[0021] The orientation-regulating structure may exert an orientation-regulating force for orienting the liquid crystal molecules into a radially-inclined orientation even in the absence of an applied voltage.

[0022] The orientation-regulating structure may be a protrusion protruding from the second substrate into the liquid crystal layer.

[0023] The orientation-regulating structure may include a surface having a horizontal alignment power provided on one side of the second substrate which is closer to the liquid crystal layer.

[0024] The orientation-regulating structure may exert an orientation-regulating force for orienting the liquid crystal molecules into a radially-inclined orientation only in the presence of an applied voltage.

[0025] The orientation-regulating structure may include an opening provided in the second electrode.

[0026] The liquid crystal display device may further include a pair of polarizing plates provided so as to oppose each other via the liquid crystal layer, wherein the pair of polarizing plates are arranged in a crossed-Nicols state.

[0027] Preferably, the liquid crystal display device further includes a pair of quarter-wave plates provided so as to oppose each other via the liquid crystal layer, wherein each of the pair of quarter-wave plates is provided between the liquid crystal layer and a respective one of the pair of polarizing plates.

[0028] More preferably, the liquid crystal display device further includes a pair of half-wave plates provided so as to oppose each other via the liquid crystal layer, wherein each of the pair of half-wave plates is provided between a respective one of the pair of polarizing plates and a respective one of the pair of quarter-wave plates.

[0029] Preferably, slow axes of the pair of quarter-wave plates are arranged so as to be perpendicular to each other.

[0030] Preferably, slow axes of the pair of half-wave plates are arranged so as to be perpendicular to each other.

[0031] Preferably, the liquid crystal layer in each of the plurality of picture element regions takes a spiral orientation in response to a voltage applied between the first electrode and the second electrode.

[0032] More preferably, the liquid crystal layer in each of the plurality of picture element regions includes a minute region which takes a twist orientation along the liquid crystal layer in response to the voltage applied between the first electrode and the second electrode.

[0033] The first substrate may further include an active element for each of the plurality of picture element regions; and the first electrode may be a picture element electrode which is provided for each of the plurality of picture element regions and is switched by the active element, and the second electrode may be at least one counter electrode opposing the plurality of picture element regions. Typically, the counter electrode is a single electrode.

[0034] Another liquid crystal display device of the present invention includes: a first substrate, a second substrate, and a liquid crystal layer provided between the first substrate and the second substrate; and a plurality of picture element regions each defined by a first electrode provided on one side of the first substrate which is closer to the liquid crystal layer and a second electrode provided on the second substrate so as to oppose the first electrode via the liquid crystal layer, wherein: the first electrode includes a lower conductive layer, a dielectric layer covering at least a portion of the lower conductive layer, and an upper conductive layer provided on one side of the dielectric layer which is closer to the liquid crystal layer; and in each of the plurality of picture element regions, the upper conductive layer includes a plurality of openings and a solid portion, the liquid crystal layer taking a vertical alignment in the absence of an applied voltage between the first electrode and the second electrode, a plurality of liquid crystal domains being formed in the plurality of openings or in the solid portion by inclined electric fields produced at respective edge portions of the plurality of openings of the upper conductive layer in response to a voltage applied between the first electrode and the second electrode, each of the plurality of liquid crystal domains taking a radially-inclined orientation, and an orientation of each of the plurality of liquid crystal domains changing according to the applied voltage, thereby producing a display.

[0035] Preferably, at least some of the plurality of openings have substantially the same shape and substantially the same size, and form at least one unit lattice arranged so as to have rotational symmetry.

[0036] Preferably, a shape of each of the at least some of the plurality of openings has rotational symmetry.

[0037] Each of the at least some of the plurality of openings may have a generally circular shape.

[0038] The solid portion may include a plurality of unit solid portions each of which is substantially surrounded by the at least one opening, and each of the plurality of unit solid portions may have a generally circular shape.

[0039] Preferably, in each of the plurality of picture element regions, a total area of the plurality of openings of the first electrode is smaller than an area of the solid portion of the first electrode.

[0040] The liquid crystal display device may further include a protrusion within each of the plurality of openings, the protrusion having the same cross-sectional shape in a plane of the first substrate as that of the plurality of openings, a side surface of the protrusion having an orientation-regulating force of the same direction with respect to liquid crystal molecules of the liquid crystal layer as a direction of orientation regulation by the inclined electric field.

[0041] The first substrate may further include an active element provided for each of the plurality of picture element regions; and the first electrode may be a picture element electrode which is provided for each of the plurality of picture element regions and is switched by the active element, and the second electrode may be at least one counter electrode opposing the plurality of picture element regions. Typically, the counter electrode is a single electrode.

[0042] Another liquid crystal display device of the present invention includes: a first substrate, a second substrate, and a liquid crystal layer provided between the first substrate and the second substrate; and a plurality of picture element regions each defined by a first electrode provided on one side of the first substrate which is closer to the liquid crystal layer and a second electrode provided on the second substrate so as to oppose the first electrode via the liquid crystal layer, wherein: in each of the plurality of picture element regions, the liquid crystal layer takes a vertical alignment in the absence of an applied voltage between the first electrode and the second electrode, and changes its orientation according to a voltage applied between the first electrode and the second electrode; the first electrode includes a lower conductive layer, a first dielectric layer including a first opening, a second dielectric layer provided on the lower conductive layer and the first dielectric layer, and an upper conductive layer provided on one side of the second dielectric layer which is closer to the liquid crystal layer; and the upper conductive layer includes at least one conductive layer opening, the lower conductive layer being provided so as to oppose at least a portion of the at least one conductive layer opening via the second dielectric layer, the first opening being provided so as to correspond to the conductive layer opening, and a height of a surface of the second dielectric layer being smaller in the conductive layer opening than in a region where the upper conductive layer is provided.

[0043] The first dielectric layer may be provided on the lower conductive layer, and the first opening may be formed so as to expose a portion of the lower conductive layer.

[0044] The first dielectric layer may be provided under the lower conductive layer, and the lower conductive layer may be provided so as to cover the first opening.

[0045] The first substrate may further include a third dielectric layer under the lower conductive layer, and the third dielectric layer may include a second opening in a region corresponding to the conductive layer opening.

[0046] The first substrate may further include a thin film transistor, and the third dielectric layer may also function as a gate insulating film of the thin film transistor.

[0047] A method of the present invention is a method for producing a liquid crystal display device, the liquid crystal display device including a first substrate, a second substrate, a liquid crystal layer provided between the first substrate and the second substrate, and a plurality of picture element regions each defined by a first electrode provided on one side of the first substrate which is closer to the liquid crystal layer and a second electrode provided on the second substrate so as to oppose the first electrode via the liquid crystal layer, wherein: the first electrode includes a lower conductive layer, a first dielectric layer including a first opening, a second dielectric layer provided on the lower conductive layer and the first dielectric layer, and an upper conductive layer provided on one side of the second dielectric layer which is closer to the liquid crystal layer; and the upper conductive layer includes at least one conductive layer opening, the lower conductive layer being provided so as to oppose at least a portion of the at least one conductive layer opening via the second dielectric layer, the step of providing the first electrode including the steps of: providing a lower conductive layer on a substrate; providing a first dielectric layer including a first opening on the substrate; providing a second dielectric layer on the lower conductive layer and the first dielectric layer, wherein a height of the second dielectric layer is greater in a region corresponding to the first opening than in other regions; and providing an upper conductive layer including a conductive layer opening on the second dielectric layer in the region corresponding to the first opening.

[0048] The first dielectric layer may be provided on the lower conductive layer so that the lower conductive layer is exposed through the first opening.

[0049] The lower conductive layer may be provided on the first dielectric layer so as to cover at least the first opening of the first dielectric layer.

[0050] The method may further include, before the step of providing the lower conductive layer, the step of providing a third dielectric layer including a second opening on the substrate.

[0051] The method may further include the step of providing a thin film transistor on the substrate, wherein the third dielectric layer is provided so as to also function as a gate insulating film of the thin film transistor.

[0052] Another method of the present invention is a method for producing a liquid crystal display device, the liquid crystal display device including a first substrate, a second substrate, a liquid crystal layer provided between the first substrate and the second substrate, and a plurality of picture element regions each defined by a first electrode provided on one side of the first substrate which is closer to the liquid crystal layer and a second electrode provided on the second substrate so as to oppose the first electrode via the liquid crystal layer, wherein: the first electrode includes a lower conductive layer, a dielectric layer covering at least a portion of the lower conductive layer, and an upper conductive layer provided on one side of the dielectric layer which is closer to the liquid crystal layer; and the upper conductive layer includes at least one conductive layer opening, and the lower conductive layer is provided so as to oppose at least a portion of the at least one conductive layer opening via the dielectric layer, the step of providing the first electrode including the steps of: providing a lower conductive layer on a substrate; providing a dielectric film on the lower conductive layer; providing an upper conductive layer including a conductive layer opening on the dielectric film; and partially removing a dielectric film in the conductive layer opening using the upper conductive layer as a mask so as to provide a dielectric layer, wherein a height of a surface of the dielectric layer is smaller in a region corresponding to the conductive layer opening than in other regions.

BRIEF DESCRIPTION OF THE DRAWINGS

[0053] Each of **FIG. 1A** to **FIG. 1C** is a cross-sectional view schematically illustrating a picture element region of a liquid crystal display device **100** according to one embodiment of the present invention.

[0054] Each of **FIG. 2**A and **FIG. 2B** is a cross-sectional view schematically illustrating a picture element region of other liquid crystal display devices **100**' and **100**", respectively, according to one embodiment of the present invention.

[0055] Each of **FIG. 3A** to **FIG. 3C** is a cross-sectional view schematically illustrating a picture element region of a conventional liquid crystal display device **200**.

[0056] Each of **FIG. 4A** to **FIG. 4C** is a cross-sectional view schematically illustrating a picture element region of a liquid crystal display device **300** for comparison.

[0057] **FIG. 5A** to **FIG. 5D** schematically illustrate the relationship between an electric force line and an orientation of a liquid crystal molecule.

[0058] **FIG. 6A** to **FIG. 6C** schematically illustrate an orientation of liquid crystal molecules in a liquid crystal display device according to one embodiment of the present invention as viewed from the substrate normal direction.

[0059] **FIG. 7**A and **FIG. 7B** schematically illustrate exemplary radially-inclined orientations of liquid crystal molecules having spiral patterns.

[0060] **FIG. 8A** to **FIG. 8C** schematically illustrate exemplary radially-inclined orientations of liquid crystal molecules.

[0061] **FIG. 9A** to **FIG. 9C** schematically illustrate an orientation of liquid crystal molecules in a liquid crystal display device according to one embodiment of the present invention as viewed from the substrate normal direction.

[0062] **FIG. 10**A and **FIG. 10B** schematically illustrate exemplary radially-inclined orientations of liquid crystal molecules.

[0063] **FIG. 11A** to **FIG. 11C** are cross-sectional views illustrating a picture element region of a liquid crystal display device **400** according to one embodiment of the present invention.

[0064] **FIG. 12A** to **FIG. 12C** schematically illustrate the relationship between an arrangement of a plurality of square openings and an orientation of liquid crystal molecules.

[0065] **FIG. 13A** to **FIG. 13C** schematically illustrate the relationship between an arrangement of a plurality of circular openings and an orientation of liquid crystal molecules.

[0066] **FIG. 14** schematically illustrates the relationship between another arrangement of a plurality of circular openings and an orientation of liquid crystal molecules.

[0067] **FIG. 15**A and **FIG. 15B** schematically illustrate a picture element region of a liquid crystal display device **400**A according to Embodiment 1 of the present invention, wherein **FIG. 15A** is a plan view, and **FIG. 15B** is a cross-sectional view taken along line **15**B-**15**B' of **FIG. 15A**.

[0068] **FIG. 16A** to **FIG. 16C** schematically illustrate exemplary radially-inclined orientations of liquid crystal molecules.

[0069] **FIG. 17**A and **FIG. 17B** are plan views schematically illustrating other picture element electrodes used in the liquid crystal display device according to Embodiment 1 of the present invention.

[0070] **FIG. 18**A and **FIG. 18B** are plan views schematically illustrating still other picture element electrodes used in the liquid crystal display device according to Embodiment 1 of the present invention.

[0071] **FIG. 19**A and **FIG. 19B** are plan views schematically illustrating still other picture element electrodes used in the liquid crystal display device according to Embodiment 1 of the present invention.

[0072] **FIG. 20** is a plan view schematically illustrating still another alternative picture element electrode used in the liquid crystal display device according to Embodiment 1 of the present invention.

[0073] **FIG. 21**A and **FIG. 21B** are plan views schematically illustrating still another picture element electrode used in the liquid crystal display device according to Embodiment 1 of the present invention.

[0074] **FIG. 22A** schematically illustrates a unit lattice of the pattern illustrated in **FIG. 15**A, **FIG. 22B** schematically illustrates a unit lattice of the pattern illustrated in **FIG. 20**, and FIG. **22**C is a graph illustrating the relationship between a pitch p and a solid portion area ratio.

[0075] **FIG. 23**A and **FIG. 23B** schematically illustrate a picture element region of a liquid crystal display device **400**B according to Embodiment 2 of the present invention, wherein **FIG. 23A** is a plan view, and **FIG. 23B** is a cross-sectional view taken along line **23**B-**23**B' of **FIG. 23A**.

[0076] **FIG. 24A** to **FIG. 24D** schematically illustrate the relationship between an orientation of liquid crystal molecules **30***a* and a surface configuration having a vertical alignment power.

[0077] **FIG. 25**A and **FIG. 25B** illustrate a state in the presence of an applied voltage across a liquid crystal layer **30**, wherein **FIG. 25A** schematically illustrates a state where an orientation has just started to change (initial ON state), and **FIG. 25B** schematically illustrates a steady state.

[0078] **FIG. 26A** to **FIG. 26C** are cross-sectional views schematically illustrating liquid crystal display devices **400**C, **400**D and **400**E, respectively, of Embodiment 2 having different relationships between an opening and a protrusion.

[0079] **FIG. 27** is a cross-sectional view schematically illustrating the liquid crystal display device **400**B taken along line **27**A-**27**A' of **FIG. 23A**.

[0080] **FIG. 28**A and **FIG. 28B** schematically illustrate a picture element region of a liquid crystal display device **400**F according to Embodiment 2 of the present invention, wherein **FIG. 28A** is a plan view, and **FIG. 28B** is a cross-sectional view taken along line **28**A-**28**A' of **FIG. 28A**.

[0081] **FIG. 29A** to **FIG. 29E** each schematically illustrate a counter substrate **200***b* including a second orientation-regulating structure **28**.

[0082] **FIG. 30**A and **FIG. 30B** schematically illustrate a liquid crystal display device **400G** including a first orientation-regulating structure and a second orientation-regulating structure, wherein **FIG. 30A** is a plan view, and **FIG. 30B** is a cross-sectional view taken along line **30**B-**30**B' of **FIG. 30A**.

[0083] **FIG. 31A** to **FIG. 31C** are cross-sectional views schematically illustrating a picture element region of the liquid crystal display device **400**G, wherein **FIG. 31A** illustrates a state in the absence of an applied voltage, **FIG. 31B** illustrates a state where an orientation has just started to change (initial ON state), and **FIG. 31C** illustrates a steady state.

[0084] **FIG. 32**A and **FIG. 32B** schematically illustrate another liquid crystal display device **400H** including a first orientation-regulating structure and a second orientation-regulating structure, wherein **FIG. 32A** is a plan view, and **FIG. 32B** is a cross-sectional view taken along line **32**B-**32**B' of **FIG. 32A**.

[0085] **FIG. 33A** to **FIG. 33C** are cross-sectional views schematically illustrating a picture element region of the liquid crystal display device **400**H, wherein **FIG. 33A** illustrates a state in the absence of an applied voltage, **FIG. 33B** illustrates a state where an orientation has just started to change (initial ON state), and **FIG. 33C** illustrates a steady state.

[0086] **FIG. 34A** to **FIG. 34C** are cross-sectional views schematically illustrating a picture element region of a liquid crystal display device **500** according to one embodiment of the present invention.

[0087] **FIG. 35** is a cross-sectional view schematically illustrating a picture element region of a liquid crystal display device **600** according to one embodiment of the present invention.

[0088] Each of **FIG. 36**A and **FIG. 36B** is an enlarged cross-sectional view schematically illustrating a structure around a picture element electrode in a liquid crystal display device according to one embodiment of the present invention.

[0089] **FIG. 37A** is a cross-sectional view schematically illustrating a picture element region of a liquid crystal display device **700** according to one embodiment of the present invention, and **FIG. 37B** is a plan view thereof.

[0090] **FIG. 38A** is a cross-sectional view schematically illustrating a picture element region of a two-way liquid crystal display device **150** according to one embodiment of the present invention.

[0091] **FIG. 38B** is a cross-sectional view schematically illustrating a picture element region of a two-way liquid crystal display device **550** according to one embodiment of the present invention.

[0092] **FIG. 38C** is a cross-sectional view schematically illustrating a picture element region of a two-way liquid crystal display device **650** according to one embodiment of the present invention.

[0093] **FIG. 39**A and **FIG. 39B** schematically illustrate a structure around an opening in a two-way liquid crystal display device according to one embodiment of the present invention.

[0094] **FIG. 40**A and **FIG. 40B** schematically illustrate a structure around an opening in a two-way liquid crystal display device according to one embodiment of the present invention.

[0095] **FIG. 41**A and **FIG. 41B** illustrate an orientation of liquid crystal molecules and an arrangement of polarizing plates in a liquid crystal display device according to one embodiment of the present invention (in the absence of an applied voltage).

[0096] **FIG. 42**A and **FIG. 42B** illustrate an orientation of liquid crystal molecules and an arrangement of polarizing plates in a liquid crystal display device according to one embodiment of the present invention (in the presence of an applied voltage).

[0097] **FIG. 43**A and **FIG. 43B** illustrate an orientation of liquid crystal molecules and an arrangement of polarizing plates and λ/4 plates in a liquid crystal display device according to one embodiment of the present invention (in the absence of an applied voltage).

[0098] **FIG. 44**A and **FIG. 44B** illustrate an orientation of liquid crystal molecules and an arrangement of polarizing plates and λ/4 plates in a liquid crystal display device according to one embodiment of the present invention (in the presence of an applied voltage).

[0099] **FIG. 45**A and **FIG. 45B** illustrate an orientation of liquid crystal molecules and another arrangement of polarizing plates and λ/4 plates in a liquid crystal display device according to one embodiment of the present invention (in the absence of an applied voltage).

[0100] **FIG. 46A** to **FIG. 46C** illustrate an orientation of liquid crystal molecules and an arrangement of polarizing plates, λ/4 plates and λ/2 plates in a liquid crystal display device according to one embodiment of the present invention (in the absence of an applied voltage).

[0101] **FIG. 47A** to **FIG. 47C** illustrate an orientation of liquid crystal molecules and another arrangement of polarizing plates, λ/4 plates and λ/2 plates in a liquid crystal display device according to one embodiment of the present invention (in the absence of an applied voltage).

[0102] **FIG. 48** is a cross-sectional view schematically illustrating a transmission type liquid crystal display device **800** according to Example 1 of the present invention.

[0103] **FIG. 49** is a plan view schematically illustrating the transmission type liquid crystal display device **800** according to Example 1 of the present invention

[0104] **FIG. 50A** to **FIG. 50E** are cross-sectional views schematically illustrating a sequence of production steps of the liquid crystal display device **800**.

[0105] **FIG. 50F** to **FIG. 50K** are cross-sectional views schematically illustrating another sequence of production steps of the liquid crystal display device **800**.

[0106] **FIG. 51** schematically illustrates the appearance of picture element regions in the presence of an applied voltage across a liquid crystal layer of the liquid crystal display device **800**.

[0107] **FIG. 52** is a cross-sectional view schematically illustrating the transmission type liquid crystal display device **900** according to Example 2 of the present invention.

[0108] **FIG. 53** is a plan view schematically illustrating a transmission type liquid crystal display device **900** according to Example 2 of the present invention.

[0109] **FIG. 54** is a cross-sectional view schematically illustrating a two-way liquid crystal display device **1000** according to Example 3 of the present invention.

[0110] **FIG. 55** is a plan view schematically illustrating the two-way liquid crystal display device **1000** according to Example 3 of the present invention.

[0111] Each of **FIG. 56**A and **FIG. 56B** is a cross-sectional view schematically illustrating a production step of the liquid crystal display device **1000**.

[0112] **FIG. 57** schematically illustrates a display operation when a voltage is applied across a liquid crystal layer in a reflection region of the liquid crystal display device **1000**.

[0113] **FIG. 58** is a cross-sectional view schematically illustrating a two-way liquid crystal display device **1100** according to Example 4 of the present invention.

[0114] **FIG. 59A** schematically illustrates an edge portion of an opening **103***a* of a photosensitive resin layer **103** in the liquid crystal display device **1000**, and **FIG. 59B** schematically illustrates an edge portion of a depressed portion **103***b* of the photosensitive resin layer **103** in the liquid crystal display device **1100**.

[0115] **FIG. 60** is a plan view schematically illustrating a portion of an upper conductive layer **104** of the liquid crystal display device **900** according to Example 2 of the present invention.

[0116] **FIG. 61** schematically illustrates an arrangement of openings provided in the vicinity of a side of the upper conductive layer **104** of a liquid crystal display device according to Example 5 of the present invention.

[0117] **FIG. 62** schematically illustrates an arrangement of openings provided in the vicinity of a corner of the upper conductive layer **104** of the liquid crystal display device according to Example 5 of the present invention.

[0118] **FIG. 63** schematically illustrates an arrangement of openings provided in the vicinity of a cut-out portion of the upper conductive layer **104** of the liquid crystal display device according to Example 5 of the present invention.

[0119] **FIG. 64** schematically illustrates an arrangement of openings in the upper conductive layer **104** of a liquid crystal display device according to Example 6 of the present invention.

[0120] **FIG. 65** schematically illustrates another arrangement of openings in the upper conductive layer **104** of the liquid crystal display device according to Example 6 of the present invention.

[0121] **FIG. 66** is a plan view schematically illustrating a liquid crystal display device **1200** according to Example 7 of the present invention.

[0122] **FIG. 67** is a cross-sectional view schematically illustrating the liquid crystal display device **1200** according to Example 7 of the present invention.

[0123] **FIG. 68** is a plan view schematically illustrating a picture element region of a liquid crystal display device **1500** according to Example 8 of the present invention.

[0124] **FIG. 69** is a cross-sectional view schematically illustrating a picture element region of the liquid crystal display device **1500** of Example 8.

[0125] **FIG. 70** is a cross-sectional view schematically illustrating a picture element region of a liquid crystal display device **1500'** of Example 8.

[0126] **FIG. 71** is a cross-sectional view schematically illustrating a picture element region of a liquid crystal display device **1500"** of Example 8.

[0127] **FIG. 72A** to **FIG. 72E** are cross-sectional views illustrating a production process of a TFT substrate **1500***a* of the liquid crystal display device **1500** of Example 8.

[0128] **FIG. 73A** to **FIG. 73E** are cross-sectional views illustrating a production process of a TFT substrate **1500***a'*of the liquid crystal display device **1500'** of Example 8.

[0129] **FIG. 74A** to **FIG. 74E** are cross-sectional views illustrating a production process of a TFT substrate **1500***a"*of the liquid crystal display device **1500"** of Example 8.

[0130] **FIG. 75** is a cross-sectional view schematically illustrating a picture element region of a liquid crystal display device **1600** of Example 9.

[0131] **FIG. 76A** to **FIG. 76E** are cross-sectional views illustrating a production process of a TFT substrate **1600***a* of the liquid crystal display device **1600** of Example 9.

DETAILED DESCRIPTION OF THE INVENTION

[**0132**] Hereinafter, preferred embodiments of the present invention will be described with reference to the accompanying drawings, in which the same reference numerals denote the same components throughout the following embodiments.

EMBODIMENT 1

[**0133**] First, the electrode structure of the liquid crystal display device of the present invention and the function thereof will be described. The liquid crystal display device of the present invention has desirable display characteristics and is therefore suitably used as an active matrix type liquid crystal display device. While the preferred embodiments of the present invention will be hereinafter described with respect to an active matrix type liquid crystal display device using thin film transistors (TFTs), the present invention can alternatively be used with an active matrix type liquid crystal display device using an MIM (metal-insulator-metal) structure, or a passive matrix type liquid crystal display device. Moreover, while the preferred embodiments of the present invention will be described with respect to a transmission type liquid crystal display device, the present invention can alternatively be used with a reflection type liquid crystal display device or even with a transmission-reflection type liquid crystal display device which will be described below.

[**0134**] In the present specification, a region of a liquid crystal display device corresponding to a "picture element", which is the minimum unit of display, will be referred to as a "picture element region". In a color liquid crystal display device, R, G and B "picture elements" correspond to one "pixel". In an active matrix type liquid crystal display device, a picture element region is defined by a picture element electrode and a counter electrode which opposes the picture element electrode. In a passive matrix type liquid crystal display device, a picture element region is defined as a region where one of column electrodes which are arranged in a stripe pattern crosses one of row electrodes which are also arranged in a stripe pattern perpendicular to the column electrodes In an arrangement with a black matrix, strictly speaking, a picture element region is a portion of each region across which a voltage is applied according to the intended display state which corresponds to an opening of the black matrix.

[**0135**] Each of **FIG. 1A** to **FIG. 1C** schematically illustrates a cross section of one picture element region of a liquid crystal display device **100** according to one embodiment of the present invention. In the following description, a color filter and a black matrix are omitted for the sake of simplicity. Moreover, in subsequent figures, each element having substantially the same function as the corresponding element in the liquid crystal display device **100** will be denoted by the same reference numeral and will not be further described below. While **FIG. 1A** to **FIG. 1C** show one picture element region of the liquid crystal display device **100** for the sake of simplicity, the liquid crystal display device of the present invention may include at least one such electrode structure as illustrated in **FIG. 1A** to **FIG. 1C** in each picture element region, as will be more fully described later.

[**0136**] The liquid crystal display device **100** includes an active matrix substrate (hereinafter, referred to as a "TFT substrate") **100***a,* a counter substrate (referred to also as a "color filter substrate") **100***b,* and a liquid crystal layer **30** provided between the TFT substrate **100***a* and the counter substrate **100***b*. Liquid crystal molecules **30***a* of the liquid crystal layer **30** have a negative dielectric anisotropy, and are aligned vertical to the surface of the vertical alignment film, as illustrated in **FIG. 1**A, in the absence of an applied voltage across the liquid crystal layer **30** by virtue of a vertical alignment layer (not shown) which is provided on one surface of each of the TFT substrate **100***a* and the counter substrate **100***b* which is closer to the liquid crystal layer **30**. This state is described as the liquid crystal layer **30** being in a vertical alignment. Note, however, that the liquid crystal molecules **30***a* of the liquid crystal layer **30** in a vertical alignment may slightly incline from the normal to the surface of the vertical alignment film (the surface of the substrate) depending upon the type of vertical alignment film or the type of liquid crystal material used. Generally, a vertical alignment is defined as a state where the axis of the liquid crystal molecules (referred to also as the "axial orientation") is oriented at an angle of about 85° or more with respect to the surface of the vertical alignment film.

[**0137**] The TFT substrate **100***a* of the liquid crystal display device **100** includes a transparent substrate (e.g., a glass substrate) **11** and a picture element electrode **15** provided on the surface of the transparent substrate **11**. The counter substrate **100***b* includes a transparent substrate (e.g., a glass substrate) **21** and a counter electrode **22** provided on the surface of the transparent substrate **21**. The orientation of the liquid crystal layer **30** changes for each picture element region according to the voltage applied between the picture element electrode **15** and the counter electrode **22** which are arranged so as to oppose each other via the liquid crystal layer **30**. A display is produced by utilizing a phenomenon that the polarization or amount of light passing through the liquid crystal layer **30** changes along with the change in the orientation of the liquid crystal layer **30**.

[**0138**] The picture element electrode **15** of the liquid crystal display device **100** includes a lower conductive layer **12**, a dielectric layer **13** covering at least a portion of the lower conductive layer **12**, and an upper conductive layer **14** provided on one side of the dielectric layer **13** which is closer to the liquid crystal layer **30**. In the liquid crystal display device **100** illustrated in **FIG. 1A** to **FIG. 1**C, the lower conductive layer **12** is provided so as to entirely cover the region of the substrate **11** opposing an opening **14***a* (area of the lower conductive layer **12**>area of the opening **14***a*).

[**0139**] The structure of the picture element electrode **15** of the liquid crystal display device of the present embodiment is not limited to the illustrated example. Alternatively, the lower conductive layer **12** may be provided so as to cover only the region of the substrate **11** opposing the opening **14***a* (area of the lower conductive layer **12**=area of the opening **14***a*), as in a liquid crystal display device **100**' illustrated in **FIG. 2A**. Alternatively, the lower conductive layer **12** may be provided so as to cover a smaller region within the region of the substrate **11** opposing the opening **14***a* (area of the lower conductive layer **12**<area of the opening **14***a*), as in a liquid crystal display device **100**" illustrated in **FIG. 2B**. Thus, the structure of the lower conductive layer **12** is not limited to any particular structure as long as the lower

conductive layer **12** opposes at least a portion of the opening **14***a* via the dielectric layer **13**. However, when the lower conductive layer **12** is provided so as to cover a smaller region within the region of the substrate **11** opposing the opening **14***a* (**FIG. 2B**), there is a region (gap region) in the plane of the substrate **11** in which neither the lower conductive layer **12** nor the upper conductive layer **14** is present as viewed in the normal direction (or "substrate normal direction", i.e., the direction normal to the substrate plane). A sufficient voltage may not be applied across the liquid crystal layer **30** in the region opposing the gap region. In order to stabilize the orientation of the liquid crystal layer **30**, it is preferred that the width of the gap region (WS in **FIG. 2B**) is sufficiently reduced. Typically, it is preferred that WS does not exceed about 4 μm.

[0140] The picture element electrode **15** including the lower conductive layer **12** and the upper conductive layer **14** is referred to also as a "two-layer electrode". The terms "lower layer" and "upper layer" are used herein merely to describe the structure of the two electrode, the lower conductive layer **12** and the upper conductive layer **14**, with respect to the dielectric layer **13**, and the terms are not to limit the placement of the liquid crystal display device in use. Moreover, the term "two-layer electrode" is not to exclude a structure having any electrode(s) other than the lower conductive layer **12** and the upper conductive layer **14**, and the term refers to any electrode structure as long as it includes at least the lower conductive layer **12** and the upper conductive layer **14** and has the function which will be described below. Moreover, the two-layer electrode does not have to be a picture element electrode in a TFT type liquid crystal display device, and may alternatively be used with any other type of liquid crystal display device as long as it includes a two-layer electrode for each picture element region. More specifically, if, for example, a column electrode (signal electrode) in a passive matrix type liquid crystal display device has a two-layer structure for each picture element region, the column electrode in each picture element region will function as the two-layer electrode as used herein.

[0141] Next, referring to **FIG. 1A** to **FIG. 1**C, **FIG. 3A** to **FIG. 3**C and **FIG. 4A** to **FIG. 4**C, the operation of the liquid crystal display device including the two-layer electrode will be described in comparison with the operation of a liquid crystal display device having a different electrode structure.

[0142] First, the operation of the liquid crystal display device **100** will be described with reference to **FIG. 1A** to **FIG. 1C**.

[0143] **FIG. 1A** schematically illustrates an orientation of the liquid crystal molecules **30***a* in the liquid crystal layer **30** in the absence of an applied voltage (OFF state). **FIG. 1B** schematically illustrates a state where the orientation of the liquid crystal molecules **30***a* has just started to change (initial ON state) according to the voltage applied across the liquid crystal layer **30**. **FIG. 1C** schematically illustrates a state where the orientation of the liquid crystal molecules **30***a* which has changed and become steady according to the applied voltage. **FIG. 1A** to **FIG. 1C** illustrate an example where the same voltage is applied across the lower conductive layer **12** and the upper conductive layer **14** of the picture element electrode **15** for the sake of simplicity. Curves EQ in **FIG.** 1B and **FIG. 1C** denote equipotential lines.

[0144] As illustrated in **FIG. 1**A, when the picture element electrode **15** and the counter electrode **22** are at the same potential (a state where no voltage is applied across the liquid crystal layer **30**), the liquid crystal molecules **30***a* in each picture element region are aligned vertical to the surfaces of the substrates **11** and **21**.

[0145] When a voltage is applied across the liquid crystal layer **30**, a potential gradient represented by the equipotential lines EQ shown in **FIG. 1B** (perpendicular to the electric force line) is produced. A uniform potential gradient represented by equipotential lines EQ parallel to the surfaces of the upper conductive layer **14** and the counter electrode **22** is produced in the liquid crystal layer **30** in a region between the upper conductive layer **14** of the picture element electrode **15** and the counter electrode **22**. A potential gradient according to the potential difference between the lower conductive layer **12** and the counter electrode **22** is produced in a region of the liquid crystal layer **30** located above the opening **14***a* of the upper conductive layer **14**. The potential gradient produced in the liquid crystal layer **30** is influenced by a voltage drop (capacitance division) due to the dielectric layer **13**, whereby the equipotential lines EQ in the liquid crystal layer **30** drop in a region corresponding to the opening **14***a* (creating a "trough" in the equipotential lines EQ). A portion of an equipotential line EQ being drawn into the dielectric layer **13** in a region corresponding to the opening **14***a* indicates that a voltage drop (capacitance division) has occurred due to the dielectric layer **13**. Since the lower conductive layer **12** is provided in a region opposing the opening **14***a* via the dielectric layer **13**, the liquid crystal layer **30** around the central portion of the opening **14***a* also has a potential gradient which is represented by a portion of the equipotential lines EQ parallel to the plane of the upper conductive layer **14** and the counter electrode **22** ("the bottom of the trough" of the equipotential lines EQ). An inclined electric field represented by an inclined portion of the equipotential lines EQ is produced in the liquid crystal layer **30** above an edge portion EG of the opening **14***a* (the peripheral portion of and within the opening **14***a* including the boundary thereof).

[0146] A torque acts upon the liquid crystal molecules **30***a* having a negative dielectric anisotropy so as to direct the axial orientation of the liquid crystal molecules **30***a* to be parallel to the equipotential lines EQ (perpendicular to the electric force line). Therefore, the liquid crystal molecules **30***a* above the right edge portion EG in **FIG. 1B** incline (rotate) clockwise and the liquid crystal molecules **30***a* above the left edge portion EG incline (rotate) counterclockwise as indicated by arrows in **FIG. 1B**. As a result, the liquid crystal molecules **30***a* above the edge portions EG are oriented parallel to the corresponding portions of the equipotential lines EQ.

[0147] Referring to **FIG. 5A** to **FIG. 5**D, the change in the orientation of the liquid crystal molecules **30***a* will now be described in greater detail.

[0148] When an electric field is produced in the liquid crystal layer **30**, a torque acts upon the liquid crystal molecules **30***a* having a negative dielectric anisotropy so as to direct the axial orientation thereof to be parallel to an equipotential line EQ. As illustrated in **FIG. 5**A, when an electric field represented by an equipotential line EQ perpendicular to the axial orientation of the liquid crystal molecule **30***a* is produced, either a torque urging the liquid crystal molecule **30***a* to incline clockwise or a torque urging the liquid crystal molecule **30***a* to incline counterclockwise occurs with the same probability. Therefore, as will be described later with reference to **FIG. 3A** to **FIG. 3**C, the liquid crystal layer **30** between the pair of parallel plate-shape electrodes opposing each other has some liquid crystal molecules **30***a* which are subject to a clockwise torque and some other liquid crystal molecules **30***a* which are subject to a counterclockwise torque. As a result, the transition to the intended orientation according to the voltage applied across the liquid crystal layer **30** may not proceed smoothly.

[**0149**] When an electric field represented by a portion of the equipotential lines EQ inclined with respect to the axial orientation of the liquid crystal molecules **30***a* (an inclined electric field) is produced at the edge portion EG of the opening **14***a* of the liquid crystal display device **100** of the present invention, as illustrated in **FIG. 1**B, the liquid crystal molecules **30***a* incline in whichever direction (the counterclockwise direction in the illustrated example) that requires less rotation for the liquid crystal molecules **30***a* to be parallel to the equipotential line EQ, as illustrated in **FIG. 5B**. The liquid crystal molecules **30***a* in a region where an electric field represented by an equipotential line EQ perpendicular to the axial orientation of the liquid crystal molecules **30***a* is produced incline in the same direction as the liquid crystal molecules **30***a* located on the inclined portion of the equipotential lines EQ so that the orientation thereof is continuous (in conformity) with the orientation of the liquid crystal molecules **30***a* located on the inclined portion of the equipotential lines EQ as illustrated in **FIG. 5C**. The phrase "being located on an equipotential line EQ" as used herein means "being located within an electric field which is represented by the equipotential line EQ".

[**0150**] The change in the orientation of the liquid crystal molecules **30***a,* starting from those which are located on the inclined portion of the equipotential lines EQ, proceeds as described above and reaches a steady state, which is schematically illustrated in **FIG. 1C**. The liquid crystal molecules **30***a* located around the central portion of the opening **14***a* are influenced substantially equally by the respective orientations of the liquid crystal molecules **30***a* at the opposing edge portions EG of the opening **14***a,* and therefore retain their orientation perpendicular to the equipotential lines EQ. The liquid crystal molecules **30***a* away from the center of the opening **14***a* incline by the influence of the orientation of other liquid crystal molecules **30***a* at the closer edge portion EG, thereby forming an inclined orientation which is symmetric about the center SA of the opening **14***a*. The orientation as viewed in a direction perpendicular to the display plane of the liquid crystal display device **100** (a direction perpendicular to the surfaces of the substrates **11** and **21**) is a state where the liquid crystal molecules **30***a* have a radial axial orientation (not shown) about the center of the opening **14***a*. In the present specification, such an orientation will be referred to as a "radially-inclined orientation".

[**0151**] In order to improve the viewing angle dependence in all azimuthal angles, the orientation of the liquid crystal molecules in each picture element region preferably has rotational symmetry about an axis perpendicular to the display plane, and more preferably axial symmetry. Therefore, the opening **14***a* is preferably arranged so that the orientation of the liquid crystal layer **30** in each picture element region has rotational symmetry (or axial symmetry). When one opening **14***a* is provided for each picture element region, the opening **14***a* is preferably provided at the center of the picture element region. Moreover, the shape of the opening **14***a* (the shape in the layer plane of the liquid crystal layer **30**) preferably has rotational symmetry (axial symmetry). Preferably, the shape of the opening **14***a* is a regular polygon such as a square, or a circle. A structure where a plurality of openings **14***a* are provided for each picture element region will be described later.

[**0152**] As described above with reference to **FIG. 1A** to **FIG. 1**C, the liquid crystal display device **100** of the present invention includes the two-layer electrode **15** for each picture element region, and an electric field represented by equipotential lines EQ having an inclined region is produced in the liquid crystal layer **30** in the picture element region. The liquid crystal molecules **30***a* having a negative dielectric anisotropy in the liquid crystal layer **30**, which are in a vertical alignment in the absence of an applied voltage, change their orientation, starting from the change in the orientation of the liquid crystal molecules **30***a* located on the inclined portion of the equipotential lines EQ (the change in the orientation of those liquid crystal molecules **30***a* serves as a trigger), and eventually form a stable radially-inclined orientation. Of course, the liquid crystal display device **100**' and the liquid crystal display device **100**", as illustrated in **FIG. 2**A and **FIG. 2**B, respectively, operate in a similar manner. If, however, the gap region WS in the structure of **FIG. 2B** is excessively large (e.g., greater than about 4 μm), a sufficient voltage may not be applied to the edge portion of the opening **14***a,* whereby the region does not contribute to the display.

[**0153**] Next, the operation of a typical conventional liquid crystal display device **200** will be described with reference to **FIG. 3A** to **FIG. 3**C, which schematically illustrate one picture element region of the liquid crystal display device **200**.

[**0154**] The liquid crystal display device **200** includes a picture element electrode **15**A and a counter electrode **22** which are arranged so as to oppose each other. The picture element electrode **15**A and the counter electrode **22** are each made of a single conductive layer which does not have the opening **14***a*.

[**0155**] As illustrated in **FIG. 3**A, the liquid crystal layer **30** takes a vertical alignment in the absence of an applied voltage across the liquid crystal layer **30**.

[**0156**] The electric field produced by application of a voltage across the liquid crystal layer **30** is represented by equipotential lines EQ which are parallel to the surfaces of the picture element electrode **15**A and the counter electrode **22** across the entire picture element region, as illustrated in **FIG. 3B**. The liquid crystal molecules **30***a* are urged to change their orientation direction so that the axial orientation thereof is parallel to the equipotential lines EQ. However, under the electric field in which the equipotential lines EQ are perpendicular to the axial orientation of the liquid crystal molecules **30***a,* the direction in which the liquid crystal molecules **30***a* are to incline (rotate) is not uniquely defined, as illustrated in **FIG. 5A**. In such a case, the liquid crystal molecules **30***a* would typically start inclining in various directions, being influenced by the local surface configurations of the vertical alignment film. As a result, the liquid crystal molecules **30***a* have different orientations in different picture element regions, whereby the liquid crystal display device **200** produces a non-uniform display. Moreover, as compared to the above-described liquid crystal display device **100** of the present invention, it requires a longer time for the orientation of the liquid crystal layer **30** to reach a steady state as illustrated in **FIG. 3C**.

[**0157**] Thus, the liquid crystal display device **100** of the present invention is capable of producing a high-quality display without non-uniformity and has a higher response speed as compared to the conventional liquid crystal display device **200**.

[**0158**] Next, the operation of a liquid crystal display device **300** having an opening **15***b* in a picture element electrode **15**B will be described with reference to **FIG. 4A** to **FIG. 4C**. The picture element electrode **15**B is different from the picture element electrode **15** of the liquid crystal display device of the present invention in that the former is made of a single electrode having the opening **15***b* and does not have the lower conductive layer **12** (see, for example, **FIG. 1A** to **FIG. 1C**). The liquid crystal display device **300** produces an inclined electric field in the liquid crystal layer **30** as does the liquid crystal display device having the opening **14***a* in the counter electrode which is disclosed in Japanese Laid-Open Patent Publication No. 6-301036 mentioned above.

[**0159**] The liquid crystal layer **30** of the liquid crystal display device **300** takes a vertical alignment in the absence of an applied voltage, as illustrated in **FIG. 4A**. The orientation of the liquid crystal layer **30** in the absence of an applied voltage is the same as that of the liquid crystal display device of the present invention (**FIG. 1A** to **FIG.** 1C and **FIG.** 2A and **FIG. 2B**) or that of the typical conventional liquid crystal display device (**FIG. 3A** to **FIG. 3C**).

[**0160**] When a voltage is applied across the liquid crystal layer **30**, an electric field represented by equipotential lines EQ shown in **FIG. 4B** is produced therein. Since the picture element electrode **15**B includes the opening **15***b* as does the picture element electrode **15** of the liquid crystal display device **100** of the present embodiment (see, for example, **FIG. 1A** to **FIG. 1C**), the equipotential lines EQ produced in the liquid crystal layer **30** of the liquid crystal display device **300** drop in a region corresponding to the opening **15***b*, thereby producing an inclined electric field represented by the inclined portion of the equipotential lines EQ in the liquid crystal layer **30** above the edge portion EG of the opening **15***b*. However, since the picture element electrode **15**B is made of a single conductive layer and does not have a lower conductive layer (at the same potential as that of the picture element electrode) in the region corresponding to the opening **15***b*, there is a region in which no electric field is produced in the liquid crystal layer above the opening **15***b* (a region in which no equipotential line EQ is drawn).

[**0161**] The liquid crystal molecules **30***a* having a negative dielectric anisotropy which is placed under such an electric field behave as follows. First, the liquid crystal molecules **30***a* above the right edge portion EG of the opening **15***b* incline (rotate) clockwise and those above the left edge portion EG incline (rotate) counterclockwise, as indicated by an arrow in **FIG.** 4B, until they reach their respective orientations parallel to the equipotential lines EQ. This is the same behavior as that of the liquid crystal molecules **30***a* in the liquid crystal display device **100** of the present embodiment described above with reference to **FIG.** 1B, and the inclination (rotation) direction of the liquid crystal molecules **30***a* in the vicinity of the edge portion EG is uniquely defined, whereby realizing a stable orientation change.

[**0162**] However, since no electric field is produced in the liquid crystal layer **30** in the region above the opening **15***b* excluding the edge portion EG, there is no torque urging the orientation thereof to change. As a result, after a sufficient amount of time has elapsed and the orientation change of the liquid crystal layer **30** has reached a steady state, the liquid crystal layer **30** in the region above the opening **15***b* excluding the edge portion EG remains in a vertical alignment as illustrated in **FIG. 4C**. Of course, some of those liquid crystal molecules **30***a* change their orientation by the influence of the orientation change of other liquid crystal molecules **30***a* in the vicinity of the edge portion EG. Still, such an influence cannot change the orientation of all the liquid crystal molecules **30***a* in the liquid crystal layer **30** above the opening **15***b*. While the distance from the edge of the opening **15***b* such an influence can be effective on the liquid crystal molecules **30***a* depends upon the thickness of the liquid crystal layer **30** and the physical properties of the liquid crystal material (e.g., the magnitude of the dielectric anisotropy, and the modulus of elasticity), the liquid crystal molecules **30***a* around the central portion of the opening **15***b* do not change their orientation by an electric field but remain in a vertical alignment when the distance between two regions where the conductive layer actually exists (referred to also as "solid portions") which lie adjacent to each other via the opening **15***b* is greater than about 4 μm. Thus, the region in the liquid crystal layer **30** of the liquid crystal display device **300** located above the opening **15***b* does not contribute to the display, thereby deteriorating the display quality. In a normally black display mode, for example, the effective aperture ratio decreases, thereby decreasing the display brightness.

[**0163**] As described above, in the liquid crystal display device **300**, the direction in which the orientation of the liquid crystal molecules **30***a* changes is uniquely defined by the inclined electric field produced in the picture element electrode **15**B having the opening **15***b*, whereby it is possible to prevent the display non-uniformity which occurs in the typical conventional liquid crystal display device **200**. However, in the liquid crystal display device **300**, the brightness is low. In contrast, since the liquid crystal display device **100** of the present embodiment includes the upper conductive layer **14** having the opening **14***a* and the lower conductive layer **12** provided so as to oppose the opening **14***a*, the electric field can act upon substantially the entire region of the liquid crystal layer **30** located above the opening **14***a*, whereby the region can contribute to the display. Therefore, the liquid crystal display device **100** of the present embodiment is capable of realizing a high-quality display with a high brightness and without non-uniformity.

[**0164**] The shape of the opening **14***a* (as viewed in the substrate normal direction) of the upper conductive layer **14** of the two-layer electrode (picture element electrode) **15** provided in the liquid crystal display device of the present embodiment will be described. The shape of the opening **14***a* may be a polygon, a circle, or an ellipse.

[0165] The display characteristics of a liquid crystal display device exhibit an azimuthal angle dependence due to the orientation (optical anisotropy) of the liquid crystal molecules. In order to reduce the azimuthal angle dependence of the display characteristics, it is preferred that the liquid crystal molecules are oriented in all azimuthal angles with substantially the same probability. More preferably, the liquid crystal molecules in each picture element region are oriented in all azimuthal angles with substantially the same probability. Therefore, the opening **14***a* preferably has a shape such that the liquid crystal molecules in each picture element region are oriented in all azimuthal angles with substantially the same probability. More specifically, the shape of the opening **14***a* preferably has rotational symmetry about a symmetry axis extending through the center of each picture element region in the normal direction. More preferably, the shape of the opening **14***a* has a high-order rotation axis, e.g., at least a two-fold rotation axis.

[0166] The orientation of the liquid crystal molecules **30***a* when the opening **14***a* has a polygonal shape will be described with reference to **FIG. 6A** to **FIG. 6C**. Each of **FIG. 6A** to **FIG. 6C** schematically illustrates the orientation of the liquid crystal molecules **30***a* as viewed in the substrate normal direction. In figures, such as **FIG. 6**B and **FIG. 6**C, illustrating the orientation of the liquid crystal molecules **30***a* as viewed in the substrate normal direction, a black-spotted end of the liquid crystal molecule **30***a* drawn as an ellipse indicates that the liquid crystal molecule **30***a* is inclined so that the end is closer than the other end to the substrate on which the two-layer electrode having the opening **14***a* is provided. This similarly applies to all of the subsequent figures.

[0167] An exemplary structure where the opening **14***a* having a rectangular shape (including a square and an oblong rectangle) is provided so as to conform with a rectangular picture element region will be described below. Cross-sectional views taken along line **1**A-**1**A' of **FIG. 6**A, line **1**B-**1**B' of **FIG. 6**B and line **1**C-**1**C' of **FIG. 6C** correspond to **FIG. 1A** to **FIG. 1**C, respectively, and **FIG. 1A** to **FIG. 1C** will also be referred to in the following description. Of course, the shape of the picture element region (picture element electrode **15**) is not limited to the illustrated example.

[0168] When the picture element electrode **15**, including the lower conductive layer **12** and the upper conductive layer **14**, and the counter electrode **22** are at the same potential, i.e., in a state where no voltage is applied across the liquid crystal layer **30**, the liquid crystal molecules **30***a* whose orientation direction is regulated by the vertical alignment layer (not shown) which is provided on one side of each of the TFT substrate **100***a* and the counter substrate **100***b* which is closer to the liquid crystal layer **30** take a vertical alignment as illustrated in **FIG. 6**A.

[0169] When an electric field is applied across the liquid crystal layer **30**, thereby producing an electric field represented by equipotential lines EQ shown in **FIG. 1A, a** torque is produced urging the axial orientation of the liquid crystal molecules **30***a* having a negative dielectric anisotropy to be parallel to the equipotential lines EQ. As described above with reference to **FIG. 5**A and **FIG. 5**B, for the liquid crystal molecules **30***a* under an electric field represented by equipotential lines EQ perpendicular to the molecular axis of the liquid crystal molecules **30***a,* the direction in which the liquid crystal molecules **30***a* are to incline (rotate) is not uniquely defined (**FIG. 5A**), whereby the change in the orientation (inclination or rotation) does not easily occur. In contrast, for the liquid crystal molecules **30***a* under equipotential lines EQ inclined with respect to the molecular axis of the liquid crystal molecules **30***a,* the direction of inclination (rotation) is uniquely defined, whereby the change in the orientation easily occurs. In the structure illustrated in **FIG. 6A** to **FIG. 6**C, the liquid crystal molecules **30***a* incline, starting from those along the four edge portions of the rectangular opening **14***a* of the upper conductive layer **14** where the molecular axis of the liquid crystal molecules **30***a* is inclined with respect to the equipotential lines EQ. Then, the surrounding liquid crystal molecules **30***a* incline so as to conform with the orientation of the already-inclined liquid crystal molecules **30***a* at the edge portion of the opening **14***a,* as described above with reference to **FIG. 5C**. Then, the axial orientation of the liquid crystal molecules **30***a* becomes stable as illustrated in **FIG. 6C** (radially-inclined orientation).

[0170] As described above, when the opening **14***a* of the upper conductive layer **14** is in the form of a rectangle, not a slit (a shape whose width is significantly smaller than its length (perpendicular to the width)), the liquid crystal molecules **30***a* in the picture element region successively incline, starting from the four edge portions of the opening **14***a* toward the center of the opening **14***a* upon application of a voltage. As a result, there is obtained an orientation in which the liquid crystal molecules **30***a* around the center of the opening **14***a,* where the respective orientation-regulating forces from the liquid crystal molecules **30***a* at the edge portions are in equilibrium, remain in a vertical alignment with respect to the substrate plane, while the surrounding liquid crystal molecules **30***a* are inclined in a radial pattern about those liquid crystal molecules **30***a* around the center of the opening **14***a,* with the degree of inclination gradually increasing away from the center of the opening **14***a*. If the liquid crystal molecules **30***a* in each picture element region take a radially-inclined orientation as described above, the liquid crystal molecules **30***a* of various axial orientations are present with substantially the same probability for all viewing angles (including azimuthal angles), whereby it is possible to realize a high-quality display without non-uniformity for all viewing angles.

[0171] Moreover, when the shape of the opening **14***a* is a square, which has a high degree of rotational symmetry (with a four-fold rotation axis), the degree of symmetry of the radially-inclined orientation of the liquid crystal molecules **30***a* about the symmetry axis at the center of the opening **14***a* is higher than that when the shape of the opening **14***a* is a rectangle, which has a low degree of rotational symmetry (with a two-fold rotation axis), whereby it is possible to realize a desirable display with even less non-uniformity for changes in the viewing angle. While a rectangle has been used as an example of the shape of the opening **14***a* in the above description, the shape of the opening **14***a* may be any other polygon, preferably a regular polygon with a high degree of rotational symmetry, as long as the liquid crystal molecules **30***a* inside the boundary of the opening **14***a* take a stable radially-inclined orientation in the presence of an applied voltage.

[0172] For the radially-inclined orientation of the liquid crystal molecules **30***a,* a radially-inclined orientation having a counterclockwise or clockwise spiral pattern as illustrated in **FIG. 8B** or **FIG.** 8C, respectively, is more stable than the simple radially-inclined orientation as illustrated in **FIG. 8A**. The spiral orientation as used herein refers to an orientation of the liquid crystal molecules in the plane of the liquid crystal layer (in the substrate plane). In a spiral orientation observed when a small amount of chiral agent is added to a liquid crystal material, the orientation direction of the liquid crystal molecules **30***a* does not substantially change in a herical pattern along the thickness of the liquid crystal layer **30** as in a normal twist orientation. In the spiral orientation, the orientation direction of the liquid crystal molecules **30***a* does not substantially change along the thickness of the liquid crystal layer **30** for a minute region. In other words, the orientation in a cross section (in a plane parallel to the layer plane) at any thickness of the liquid crystal layer **30** is as illustrated in **FIG. 8B** or **FIG.** 8C, with substantially no twist deformation along the thickness of the liquid crystal layer **30**. For the opening **14***a* as a whole, however, there may be a certain degree of twist deformation.

[0173] When a material obtained by adding a chiral agent to a nematic liquid crystal material having a negative dielectric anisotropy is used, the liquid crystal molecules **30***a* take a radially-inclined orientation of a counterclockwise or clockwise spiral pattern about the opening **14***a,* as illustrated in **FIG. 7A** or **FIG.** 7B, respectively, in the presence of an applied voltage. Whether the spiral pattern is counterclockwise or clockwise is determined by the type of chiral agent used. Thus, by controlling the liquid crystal layer **30** in the opening **14***a* into a radially-inclined orientation of a spiral pattern in the presence of an applied voltage, the direction of the spiral pattern of the radially-inclined liquid crystal molecules **30***a* about other liquid crystal molecules **30***a* standing vertical to the substrate plane can be constant in all openings **14***a,* whereby it is possible to realize a uniform display without non-uniformity. Since the direction of the spiral pattern around the liquid crystal molecules **30***a* standing vertical to the substrate plane is definite, the response speed upon application of a voltage across the liquid crystal layer **30** is also improved.

[0174] Moreover, when a larger amount of chiral agent is added, the orientation of the liquid crystal molecules **30***a* changes in a herical pattern along the thickness of the liquid crystal layer **30**, even in the liquid crystal layer of a spiral orientation with respect to a minute region thereof, as in a normal twist orientation.

[0175] In an orientation where the orientation of the liquid crystal molecules **30***a* does not change in a herical pattern along the thickness of the liquid crystal layer **30**, the liquid crystal molecules **30***a* which are oriented perpendicular or parallel to the polarization axis of the polarizing plate do not give a phase difference to the incident light, whereby incident light passing through a region of such an orientation does not contribute to the transmittance. For example, when a picture element region producing a white display is observed in the liquid crystal display device where the polarizing plates are arranged in a crossed-Nicols state, a cross-shaped extinction pattern is clearly observed in the central portion of a liquid crystal domain being in a radially-inclined orientation.

[0176] In contrast, in an orientation where the orientation of the liquid crystal molecules **30***a* changes in a herical pattern along the thickness of the liquid crystal layer **30**, the liquid crystal molecules **30***a* which are oriented perpendicular or parallel to the polarization axis of the polarizing plate also give a phase difference to the incident light, and the optical rotatory power can also be utilized, whereby incident light passing through a region of such an orientation also contributes to the transmittance. Thus, it is possible to obtain a liquid crystal display device capable of producing a bright display. For example, when a picture element region producing a white display is observed in the liquid crystal display device where the polarizing plates are arranged in a crossed-Nicols state, the cross-shaped extinction pattern in the central portion of a liquid crystal domain being in a radially-inclined orientation is unclear, thereby making the display as a whole brighter. The twist angle of the liquid crystal layer is preferably about 90° so as to efficiently improve the light efficiency due to the optical rotatory power.

[0177] The shape of the opening **14***a* is not limited to a polygon as described above, but may alternatively be a circle or an ellipse. The orientation of the liquid crystal molecules **30***a* when the shape of the opening **14***a* is a circle will be described with reference to **FIG. 9A** to **FIG. 9C**. Each of **FIG. 9A** to **FIG. 9C** schematically illustrates the orientation of the liquid crystal molecules **30***a* as viewed in the substrate normal direction. An exemplary structure where a rectangular picture element region is provided with a circular opening **14***a* will be described below. Cross-sectional views taken along line 1A-1A' of **FIG. 9**A, line 1B-1B' of **FIG. 9**B and line 1C-1C' of **FIG. 9C** correspond to **FIG. 1A** to **FIG.** 1C, respectively, and **FIG. 1A** to **FIG. 1C** will also be referred to in the following description.

[0178] When the picture element electrode **15**, including the lower conductive layer **12** and the upper conductive layer **14**, and the counter electrode **22** are at the same potential, i.e., in a state where no voltage is applied across the liquid crystal layer **30**, the liquid crystal molecules **30***a* whose orientation direction is regulated by the vertical alignment layer (not shown) which is provided on one side of each of the TFT substrate **100***a* and the counter substrate **100***b* which is closer to the liquid crystal layer **30** take a vertical alignment as illustrated in **FIG. 9A**.

[0179] When an electric field is applied across the liquid crystal layer **30** so as to produce an electric field represented by equipotential lines EQ shown in **FIG. 1A, a** torque acts upon the liquid crystal molecules **30***a* having a negative dielectric anisotropy so as to direct the axial orientation thereof to be parallel to the equipotential lines EQ. As described above with reference to **FIG.** 5A and **FIG.** 5B, for the liquid crystal molecules **30***a* under an electric field represented by equipotential lines EQ perpendicular to the molecular axis thereof, the direction in which the liquid crystal molecules **30***a* are to incline (rotate) is not uniquely defined (**FIG. 5A**), whereby the orientation change (inclination or rotation) does not easily occur. In contrast, for the liquid crystal molecules **30***a* placed under equipotential lines EQ inclined with respect to the molecular axis of the liquid crystal molecules **30***a,* the direction of inclination (rotation) is uniquely defined, whereby the orientation change easily occurs. In the structure illustrated in **FIG. 9A** to **FIG. 9C**, the liquid crystal molecules **30***a* incline, starting from the edge portion along the circumference of the circular opening **14***a* of the upper conductive layer **14** where the molecular axis of the liquid crystal molecules **30***a* is inclined with respect to the equipotential lines EQ. Then, the surrounding liquid crystal molecules **30***a* incline so as to conform with the orientation of the already-inclined liquid crystal molecules **30***a* at the edge portion of the opening **14***a,* as described above with reference to **FIG. 5C**. Then, the axial orientation of the liquid crystal molecules **30***a* becomes stable as illustrated in **FIG. 9C** (radially-inclined orientation).

[**0180**] As described above, when the opening **14***a* of the upper conductive layer **14** is in the form of a circle, the liquid crystal molecules **30***a* in the picture element region successively incline, starting from the circumferential edge portion of the opening **14***a* toward the center of the opening **14***a* upon application of a voltage. As a result, there is obtained an orientation (radially-inclined orientation) in which those liquid crystal molecules **30***a* around the center of the opening **14***a,* where the respective orientation-regulating forces from the liquid crystal molecules **30***a* at the edge portion are in equilibrium, remain in a vertical alignment with respect to the substrate plane, while the surrounding liquid crystal molecules **30***a* are inclined in a radial pattern about those liquid crystal molecules **30***a* around the center of the opening **14***a,* with the degree of inclination gradually increasing away from the center of the opening **14***a*. When the shape of the opening **14***a* is a circle, as compared when it is a rectangle, the center of the radially-inclined orientation (the position of the liquid crystal molecules **30***a* oriented vertical to the substrate plane) is stably formed at the center of the opening **14***a,* whereby it is possible to realize a high-quality display without non-uniformity in all directions in the presence of an applied voltage.

[**0181**] It is believed that the effect that the center position of the radially-inclined orientation is stabilized, which is obtained when the shape of the opening **14***a* is a circle, is due to the fact that a circle has a high degree of rotational symmetry, and the edge of the circular opening **14***a,* which determines the inclination direction of the liquid crystal molecules **30***a,* is continuous. The effect of stabilizing the radially-inclined orientation due to the continuity of the edge of the opening **14***a* can also be obtained when the shape of the opening **14***a* is an ellipse (an oblong circle).

[**0182**] As described above with reference to **FIG. 8A** to **FIG.** 8C, the radially-inclined orientation of the liquid crystal molecules **30***a* can be more stabilized by giving a spiral pattern thereto. Therefore, it is preferred to employ a radially-inclined orientation of a counterclockwise or clockwise spiral pattern about the opening **14***a,* as illustrated in **FIG. 10A** or **FIG. 10**B, respectively. Particularly, when the opening **14***a* has a large area and the distance from a side of the opening **14***a* to the center thereof is long, it is preferred to give a spiral pattern because, in such a case, the orientation of the liquid crystal molecules **30***a* located in the opening **14***a* is less likely to be stable. A spiral pattern can be given to a radially-inclined orientation by, for example, adding a chiral agent to a liquid crystal material.

STRUCTURE WITH A PLURALITY OF OPENINGS

[**0183**] In the above, the structure and function of the two-layer electrode having an opening have been described with examples where one opening is provided for each picture element region. Alternatively, a plurality of openings may be provided for each picture element region. In the following description, a structure with a two-layer picture element electrode having a plurality of openings is used for each picture element region will be described.

[**0184**] When a plurality of openings are provided for each picture element region, each of the openings preferably has a shape having rotational symmetry as described above so that the liquid crystal molecules in the picture element region take a uniform orientation in all azimuthal angles, and it is more preferred that the arrangement of the plurality of openings has rotational symmetry. The structure and operation of an exemplary liquid crystal display device including a two-layer picture element electrode in which a plurality of openings are arranged so that the openings have rotational symmetry for each picture element region will be described below.

[**0185**] Each of **FIG. 11A** to **FIG. 11C** schematically illustrates a cross-sectional structure of one picture element region of a liquid crystal display device **400** including the picture element electrode **15** having a plurality of openings **14***a* (including **14***a***1** and **14***a***2**). The liquid crystal display device **400** includes a TFT substrate **400***a* and a counter substrate **100***b* (substantially the same as the counter substrate **100***b* illustrated in **FIG. 1A** to FIG. 1C).

[**0186**] **FIG. 11A** schematically illustrates an orientation of the liquid crystal molecules **30***a* in the liquid crystal layer **30** in the absence of an applied voltage (OFF state). **FIG. 11B** schematically illustrates a state where the orientation of the liquid crystal molecules **30***a* has just started to change (initial ON state) according to the voltage applied across the liquid crystal layer **30**. **FIG. 11C** schematically illustrates a state where the orientation of the liquid crystal molecules **30***a* which has changed and become steady according to the applied voltage. **FIG. 11A** to **FIG. 11C** respectively correspond to **FIG. 1A** to **FIG. 1C** illustrating the liquid crystal display device **100** including the picture element electrode **15** having only one opening **14***a* for each picture element region. In **FIG. 11A** to **FIG.** 11C, the lower conductive layer **12**, which is provided so as to oppose the openings **14***a***1** and **14***a***2** via the dielectric layer **13**, overlaps both of the openings **14***a***1** and **14***a***2** and also extends in a region between the openings **14***a***1** and **14***a***2** (a region where the upper conductive layer **14** exists). However, the arrangement of the lower conductive layer **12** is not limited to this, as long as the lower conductive layer **12** has the positional relationship with respect to the openings **14***a***1** and **14***a***2** as illustrated in **FIG. 11A** to **FIG. 11C**. The lower conductive layer **12** which is provided at a position such that it opposes the region where the conductive layer of the upper conductive layer **14** exists via the dielectric layer **13** has substantially no influence on the electric field applied across the liquid crystal layer **30**. Therefore, such a lower conductive layer **12** may or may not be patterned.

[**0187**] As illustrated in **FIG. 11**A, when the picture element electrode **15** and the counter electrode **22** are at the same potential (a state where no voltage is applied across the liquid crystal layer **30**), the liquid crystal molecules **30***a* in the picture element region are aligned vertical to the surfaces of the substrates **11** and **21**.

[**0188**] When a voltage is applied across the liquid crystal layer **30**, a potential gradient represented by equipotential lines EQ shown in **FIG. 11B** is produced. A uniform potential gradient represented by equipotential lines EQ parallel to the surfaces of the upper conductive layer **14** and the counter electrode **22** is produced in the liquid crystal layer **30** in a region between the upper conductive layer **14** of the picture element electrode **15** and the counter electrode **22**. A potential gradient according to the potential difference between the lower conductive layer **12** and the counter electrode **22** is produced in regions of the liquid crystal layer **30** located above the openings **14**a**1** and **14**a**2** of the upper conductive layer **14**. The potential gradient produced in the liquid crystal layer **30** is influenced by a voltage drop due to the dielectric layer **13**, whereby the equipotential lines EQ in the liquid crystal layer **30** drop in regions corresponding to the openings **14**a**1** and **14**a**2** (creating a plurality of "troughs" in the equipotential lines EQ). Since the lower conductive layer **12** is provided in a region opposing the openings **14**a**1** and **14**a**2** via the dielectric layer **13**, the liquid crystal layer **30** around the respective central portions of the openings **14**a**1** and **14**a**2** also has a potential gradient which is represented by a portion of the equipotential lines EQ parallel to the plane of the upper conductive layer **14** and the counter electrode **22** ("the bottom of the trough" of the equipotential lines EQ). An inclined electric field represented by an inclined portion of the equipotential lines EQ is produced in the liquid crystal layer **30** above an edge portion EG of each of the openings **14**a**1** and **14**a**2** (the peripheral portion of and within the opening including the boundary thereof).

[0189] A torque acts upon the liquid crystal molecules **30**a having a negative dielectric anisotropy so as to direct the axial orientation of the liquid crystal molecules **30**a to be parallel to the equipotential lines EQ. Therefore, the liquid crystal molecules **30**a above the right edge portion EG in **FIG. 11B** incline (rotate) clockwise and the liquid crystal molecules **30**a above the left edge portion EG incline (rotate) counterclockwise as indicated by arrows in **FIG. 11B**. As a result, the liquid crystal molecules **30**a above the edge portions EG are oriented parallel to the corresponding portions of the equipotential lines EQ.

[0190] When an electric field represented by a portion of the equipotential lines EQ inclined with respect to the axial orientation of the liquid crystal molecules **30**a (an inclined electric field) is produced at the edge portions EG of the openings **14**a**1** and **14**a**2** of the liquid crystal display device **400** of the present invention, as illustrated in **FIG. 11**B, the liquid crystal molecules **30**a incline in whichever direction (the counterclockwise direction in the illustrated example) that requires less rotation for the liquid crystal molecules **30**a to be parallel to the equipotential line EQ, as illustrated in **FIG. 5B**. The liquid crystal molecules **30**a in a region where an electric field represented by an equipotential line EQ perpendicular to the axial orientation of the liquid crystal molecules **30**a is produced incline in the same direction as the liquid crystal molecules **30**a located on the inclined portion of the equipotential lines EQ so that the orientation thereof is continuous (in conformity) with the orientation of the liquid crystal molecules **30**a located on the inclined portion of the equipotential lines EQ as illustrated in **FIG. 5C**.

[0191] The change in the orientation of the liquid crystal molecules **30**a, starting from those which are located on the inclined portion of the equipotential lines EQ, proceeds as described above and reaches a steady state, i.e., an inclined orientation (radially-inclined orientation) which is symmetric about the center SA of each of the openings **14**a**1** and **14**a**2**, as schematically illustrated in **FIG. 11C**. The liquid crystal molecules **30**a in a region of the upper conductive layer **14** located between the two adjacent openings **14**a**1** and **14**a**2** also take an inclined orientation so that the orientation thereof is continuous (in conformity) with the orientation of the liquid crystal molecules **30**a at the edge portions of the openings **14**a**1** and **14**a**2**. The liquid crystal molecules **30**a in the middle between the edge of the opening **14**a**1** and the edge of the opening **14**a**2** are subject to substantially the same influence from the liquid crystal molecules **30**a at the respective edge portions, and thus remain in a vertical alignment as the liquid crystal molecules **30**a located around the central portion of each of the openings **14**a**1** and **14**a**2**. As a result, the liquid crystal layer above the upper conductive layer **14** between the adjacent two openings **14**a**1** and **14**a**2** also takes a radially-inclined orientation. Note that the inclination direction of the liquid crystal molecules differs between the radially-inclined orientation of the liquid crystal layer in each of the openings **14**a**1** and **14**a**2** and that of the liquid crystal layer between the openings **14**a**1** and **14**a**2**. Observation of the orientation around the liquid crystal molecule **30**a at the center of each region having the radially-inclined orientation illustrated in **FIG. 11C** shows that the liquid crystal molecules **30**a in the regions of the openings **14**a**1** and **14**a**2** are inclined so as to form a cone which spreads toward the counter electrode, whereas the liquid crystal molecules **30**a in the region between the openings are inclined so as to form a cone which spreads toward the upper conductive layer **14**. Since both of these radially-inclined orientations are formed so as to conform with the inclined orientation of the liquid crystal molecules **30**a at an edge portion, the two radially-inclined orientations are continuous with each other.

[0192] As described above, when a voltage is applied across the liquid crystal layer **30**, the liquid crystal molecules **30**a incline, starting from those above the respective edge portions EG of the openings **14**a**1** and **14**a**2** provided in the upper conductive layer **14**. Then, the liquid crystal molecules **30**a in the surrounding regions incline so as to conform with the inclined orientation of the liquid crystal molecules **30**a above the edge portion EG. Thus, a radially-inclined orientation is formed. Therefore, as the number of openings **14**a to be provided in each picture element region increases, the number of liquid crystal molecules **30**a which initially start inclining in response to an applied electric field also increases, thereby reducing the amount of time which is required to achieve the radially-inclined orientation across the entire picture element region. Thus, by increasing the number of openings **14**a to be provided in the picture element electrode for each picture element region, it is possible to improve the response speed of a liquid crystal display device.

[0193] As described above, by providing a plurality of openings **14**a**1** and **14**a**2** for each picture element region, it is possible to realize a liquid crystal display device having a desirable display quality and a desirable viewing angle characteristic in all azimuthal angles, and also to improve the response characteristic of the liquid crystal display device.

[0194] Next, the relationship between the shape and positional relationship of the plurality of openings **14***a* and the orientation of the liquid crystal molecules **30***a* will be described with reference to **FIG. 12A** to **FIG. 12**C and **FIG. 13A** to **FIG. 13C**. Cross-sectional views taken along line 11A-11A' of **FIG. 12**A and **FIG. 13**A, line 11B-11B' of **FIG. 12**B and **FIG. 13**B and line 11C-11C' of **FIG. 12C** and **FIG. 13C** correspond to **FIG. 11A** to **FIG. 11**C, respectively.

[0195] While **FIG. 12A** to **FIG. 12**C and **FIG. 13A** to **FIG. 13C** illustrate a rectangular picture element electrode **15** (picture element region), the outer shape of the picture element electrode **15** (upper conductive layer **14**) and the opening **14***a* is not limited to this. The liquid crystal display device of the present invention is not limited to including only one electrode structure as illustrated in **FIG. 12A** to **FIG. 12**C or **FIG. 13A** to **FIG. 13C** for each picture element region, but may alternatively include a plurality of electrode structures as illustrated in **FIG. 12A** to **FIG. 12C** or **FIG. 13A** to **FIG. 13C** for each picture element region. The positional relationship between the periphery of the picture element electrode **15** (upper conductive layer **14**) is not limited to any particular relationship. Alternatively, for example, a portion of the plurality of openings **14***a* may overlap a side or a corner defining the periphery of the upper conductive layer **14**. This also applies to a liquid crystal display device of any other embodiment in which a picture element region includes a plurality of openings **14***a*. A preferred positional relationship among the openings **14***a* for stabilizing the orientation of the liquid crystal molecules across the entire picture element region (and for improving the response speed) will be described later.

[0196] First, as described above, the shape of each opening **14***a* may be a polygon, a circle or an ellipse. Since it is preferred that the shape of each opening **14***a* has a high degree of rotational symmetry in order to improve the viewing angle characteristic in all azimuthal angles (eliminate the display non-uniformity) in the liquid crystal display device **400**, the shape of each opening **14***a* is preferably a regular polygon such as a square as illustrated in **FIG. 12A** to **FIG. 12C** or a circle as illustrated in **FIG. 13A** to **FIG. 13C**. The relationship between the shape of each opening **14***a* and the orientation of the liquid crystal molecules **30***a* is as described above, and will not be further described below.

[0197] In a structure where a plurality of openings **14***a* are provided for each picture element region, it is preferred that the arrangement of the plurality of openings **14***a* has rotational symmetry. For example, when four square openings **14***a* are provided in a square upper conductive layer **14** (i.e., when a picture element region has a square shape), as illustrated in **FIG. 12A** to **FIG. 12**C, the four openings **14***a* are preferably arranged so that they have rotational symmetry about the center SA of the square upper conductive layer **14**. It is preferred that the center SA of the square upper conductive layer **14** is a four-fold rotation axis, as illustrated in the figures. With such an arrangement, each region having a radially-inclined orientation which is formed about each opening **14***a* in the presence of an applied voltage across the liquid crystal layer **30**, has four-fold rotational symmetry about the center SA of the upper conductive layer **14**, as illustrated in **FIG. 12**B and **FIG. 12C**. As a result, the viewing angle characteristic of the liquid crystal display device **400** is even more uniform in all azimuthal angles.

[0198] While a structure where four openings **14***a* are provided for each picture element region is illustrated in **FIG. 12A** to **FIG. 12**C, the number of openings **14***a* is not limited to this. The number of openings **14***a* to be provided for each picture element region can be suitably determined in view of the size and shape of the picture element region, the size of a region for which a radially-inclined orientation can be stably formed by a single opening **14***a,* and the response speed. When providing a large number of openings **14***a* for each picture element region, it is preferred that the arrangement of the openings **14***a* has rotational symmetry across the entire picture element region in order to improve the uniformity of the viewing angle characteristic. However, depending upon the shape of the picture element region, it may not be possible to arrange the openings **14***a* so as to have rotational symmetry across the entire picture element region. In such a case, it is preferred that the openings **14***a* are arranged so as to have rotational symmetry across as much area as possible. For example, when the shape of the picture element region is an oblong rectangle, the oblong rectangle can be divided into squares, and a plurality of openings **14***a* can be provided so that there is rotational symmetry for each of such squares. In this way, it is possible to obtain a liquid crystal display device having a sufficiently uniform viewing angle characteristic.

[0199] **FIG. 13A** to **FIG. 13C** illustrate a structure where a circular opening **14***a* is provided instead of the square opening **14***a* as illustrated in **FIG. 12A** to **FIG. 12**C.

[0200] It is possible to further improve the viewing angle characteristic of a liquid crystal display device by arranging four openings **14***a* so that the center SA of the upper conductive layer **14** is a four-fold rotation axis as described above with reference to **FIG. 12A** to **FIG. 12C**. When the shape of each opening **14***a* is a circle, rather than a polygon, there is a higher degree of continuity of orientation of the liquid crystal molecules **30***a* at the edge portion of each opening **14***a,* whereby the radially-inclined orientation of the liquid crystal molecules **30***a* is more stable. Moreover, in a structure with a plurality of openings **14***a,* if the shape of each opening **14***a* is a circle, there is a high degree of continuity between radially-inclined orientations formed by adjacent openings **14***a,* whereby the plurality of radially-inclined orientations formed in each picture element region are more easily stabilized.

[0201] For example, when four circular openings **14***a* are arranged so that the respective centers thereof are at the respective corners of an oblong rectangle, as illustrated in **FIG. 14**, the liquid crystal molecules **30***a* located along each diagonal of the oblong rectangle can form a continuous inclined orientation. In contrast, when four square openings **14***a* are used in the arrangement illustrated in **FIG. 14**, the diagonal of the oblong rectangle formed by the respective centers of the openings **14***a* does not coincide with the diagonal of each square opening **14***a*. As can be appreciated from the above, the orientation of the liquid crystal molecules **30***a* in the region surrounded by the four openings **14***a* is less likely to be continuous. This problem can be avoided by providing four openings **14***a* each having an oblong rectangle similar to the oblong rectangle which is formed by the respective centers of the four openings **14***a*. However, the continuity of the radially-inclined orientation formed in each of the openings **14***a* decreases. Thus, the shape and arrangement of the openings **14***a* is preferably determined in view of the shape and size of the picture element region. **FIG. 14** illustrates a state in the presence of an applied voltage across the liquid crystal layer, and a cross-sectional view taken along line **11**C-**11**C' of **FIG. 14** corresponds to **FIG. 11C**.

[**0202**] A preferred arrangement of openings for an electrode structure having a plurality of openings for each picture element region (i.e., a two-layer electrode in which the picture element electrode or the counter electrode includes openings therein) will be described below in greater detail.

[**0203**] A pattern of the upper conductive layer **14** of another liquid crystal display device **400**A of Embodiment 1 will be described with reference to **FIG. 15A**. **FIG. 15B** is a cross-sectional view taken along line **15**B-**15**B' of **FIG. 15A**. The cross-sectional view of **FIG. 15B** is substantially the same as that of **FIG. 11A** except that a solid portion of the upper conductive layer **14** is denoted by a reference numeral **14***b*, and a unit solid portion thereof is denoted by a reference numeral **14***b'*.

[**0204**] The upper conductive layer **14** of the liquid crystal display device **400**A includes a plurality of openings **14***a* and a solid portion **14***b*. The opening **14***a* refers to a portion of the upper conductive layer **14** made of a conductive film (e.g., an ITO film) from which the conductive film has been removed, and the solid portion **14***b* refers to a portion thereof where the conductive film is present (the portion other than the openings **14***a*). While a plurality of openings **14***a* are formed for each picture element electrode, the solid portion **14***b* is basically made of a single continuous conductive film.

[**0205**] The openings **14***a* are arranged so that the respective centers thereof form a square lattice, and the unit solid portion **14***b'*(defined as a portion of the solid portion **14***b* which is generally surrounded by four openings **14***a* whose respective centers are located at the four lattice points which form one unit lattice) has a generally circular shape. Each opening **14***a* has a generally star shape having four quarter-arc-shaped sides (edges) with a four-fold rotation axis at the center among the four sides. In order to stabilize the orientation across the entire picture element region, the unit lattices preferably exist up to the periphery of the upper conductive layer **14**. Therefore, a peripheral portion of the upper conductive layer **14** is preferably patterned, as illustrated in the figure, into a shape which corresponds to a generally half piece of the opening **14***a* (in a peripheral portion of the upper conductive layer **14** along a side thereof) or into a shape which corresponds to a generally quarter piece of the opening **14***a* (in a peripheral portion of the upper conductive layer **14** at a corner thereof). The square shown in a solid line in **FIG. 15A** (a collection of the square lattices) represents a region (outer shape) corresponding to a conventional picture element electrode which is made of a single conductive layer.

[**0206**] The openings **14***a* located in the central portion of the picture element region have generally the same shape and size. The unit solid portions **14***b'*located respectively in unit lattices formed by the openings **14***a* are generally circular in shape, and have generally the same shape and size. Each unit solid portion **14***b'*is connected to adjacent unit solid portions **14***b'*, thereby forming the solid portion **14***b* which substantially functions as a single conductive film.

[**0207**] When a voltage is applied between the upper conductive layer **14** having such a structure as described above and the counter electrode **22**, an inclined electric field is produced at the edge portion of each opening **14***a*, thereby producing a plurality of liquid crystal domains each having a radially-inclined orientation. The liquid crystal domain is produced in each region corresponding to the opening **14***a* and in each region corresponding to the unit solid portion **14***b'*in a unit lattice.

[**0208**] While the upper conductive layer **14** having a square shape is illustrated herein, the shape of the picture element electrode **14** is not limited to this. A typical shape of the upper conductive layer **14** can be approximated to a rectangular shape (including a square and an oblong rectangle), whereby the openings **14***a* can be regularly arranged therein in a square lattice pattern. Even when the upper conductive layer **14** has a shape other than a rectangular shape, the effects of the present invention can be obtained as long as the openings **14***a* are arranged in a regular manner (e.g., in a square lattice pattern as illustrated herein) so that liquid crystal domains are formed in all regions in the picture element region.

[**0209**] The shape (as viewed in the substrate normal direction) and arrangement of the openings **14***a* of the upper conductive layer **14** of the liquid crystal display device **400**A according to the present embodiment will now be described.

[**0210**] The display characteristics of a liquid crystal display device exhibit an azimuthal angle dependence due to the orientation (optical anisotropy) of the liquid crystal molecules. In order to reduce the azimuthal angle dependence of the display characteristics, it is preferred that the liquid crystal molecules are oriented in all azimuthal angles with substantially the same probability. More preferably, the liquid crystal molecules in each picture element region are oriented in all azimuthal angles with substantially the same probability. Therefore, the opening **14***a* preferably has a shape such that liquid crystal domains are formed in each picture element region so that the liquid crystal molecules **30***a* in the picture element region are oriented in all azimuthal angles with substantially the same probability. More specifically, the shape of the opening **14***a* preferably has rotational symmetry (preferably with a high-order rotation axis, e.g., at least a two-fold rotation axis) about a symmetry axis extending through the center of each picture element region in the normal direction. It is also preferred that the plurality of openings **14***a* are arranged so as to have rotational symmetry. Moreover, it is preferred that the shape of the unit solid portion **14***b'*which is generally surrounded by these openings also has rotational symmetry. It is also preferred that the unit solid portions **14***b'*are arranged so as to have rotational symmetry.

[**0211**] However, it may not be necessary to arrange the openings **14***a* or the unit solid portions **14***b'*so as to have rotational symmetry across the entire picture element region. The liquid crystal molecules can be oriented in all azimuthal angles with substantially the same probability across the entire picture element region when, for example, a square lattice (having symmetry with a four-fold rotation axis) is used as the minimum unit, and the picture element region is formed by such square lattices, as illustrated in **FIG. 15A**.

[**0212**] The orientation of the liquid crystal molecules **30***a* when the generally star-shaped openings **14***a* having rotational symmetry and the generally circular unit solid portions **14***b*'are arranged in a square lattice pattern, as illustrated in **FIG. 15**A, will be described with reference to **FIG. 16A** to **FIG. 16C**.

[**0213**] Each of **FIG. 16A** to **FIG. 16C** schematically illustrates an orientation of the liquid crystal molecules **30***a* as viewed in the substrate normal direction. In figures, such as **FIG. 16**B and **FIG. 16**C, illustrating the orientation of the liquid crystal molecules **30***a* as viewed in the substrate normal direction, a black-spotted end of the liquid crystal molecule **30***a* drawn as an ellipse indicates that the liquid crystal molecule **30***a* is inclined so that the end is closer than the other end to the substrate on which the upper conductive layer **14** having the opening **14***a* is provided. This similarly applies to all of the subsequent figures. A single unit lattice (which is formed by four openings **14***a*) in the picture element region illustrated in **FIG. 15A** will be described below. Cross-sectional views taken along the respective diagonals of **FIG. 16A** to **FIG. 16C** correspond to **FIG. 11A** to **FIG. 11**C, respectively, and **FIG. 11A** to **FIG. 11C** will also be referred to in the following description.

[**0214**] When the upper conductive layer **14** and the counter electrode **22** are at the same potential, i.e., in a state where no voltage is applied across the liquid crystal layer **30**, the liquid crystal molecules **30***a* whose orientation direction is regulated by the vertical alignment layer (not shown) which is provided on one side of each of the TFT substrate **400***a* and the counter substrate **100***b* which is closer to the liquid crystal layer **30** take a vertical alignment as illustrated in **FIG. 16A**.

[**0215**] When an electric field is applied across the liquid crystal layer **30**, the liquid crystal molecules **30***a* incline, starting from those at the edge portion of each opening **14***a,* as illustrated in **FIG. 16B**. Then, the surrounding liquid crystal molecules **30***a* incline so as to conform with the orientation of the already-inclined liquid crystal molecules **30***a* at the edge portion of the opening **14***a*. Then, the axial orientation of the liquid crystal molecules **30***a* becomes stable as illustrated in **FIG. 16C** (radially-inclined orientation).

[**0216**] As described above, when the shape of the opening **14***a* has rotational symmetry, the liquid crystal molecules **30***a* in the picture element region successively incline, starting from the edge portion of the opening **14***a* toward the center of the opening **14***a* upon application of a voltage. As a result, there is obtained an orientation in which those liquid crystal molecules **30***a* around the center of the opening **14***a,* where the respective orientation-regulating forces from the liquid crystal molecules **30***a* at the edge portion are in equilibrium, remain in a vertical alignment with respect to the substrate plane, while the surrounding liquid crystal molecules **30***a* are inclined in a radial pattern about those liquid crystal molecules **30***a* around the center of the opening **14***a,* with the degree of inclination gradually increasing away from the center of the opening **14***a*.

[**0217**] The liquid crystal molecules **30***a* in a region corresponding to the generally circular unit solid portion **14***b*'which is surrounded by the four generally star-shaped openings **14***a* arranged in a square lattice pattern also incline so as to conform with the orientation of the liquid crystal molecules **30***a* which have been inclined by an inclined electric field produced at the edge portion of each opening **14***a*. As a result, there is obtained an orientation in which those liquid crystal molecules **30***a* around the center of the unit solid portion **14***b',* where the respective orientation-regulating forces from the liquid crystal molecules **30***a* at the edge portions are in equilibrium, remain in a vertical alignment with respect to the substrate plane, while the surrounding liquid crystal molecules **30***a* are inclined in a radial pattern about those liquid crystal molecules **30***a* around the center of the unit solid portion **14***b',* with the degree of inclination gradually increasing away from the center of the unit solid portion **14***b'*.

[**0218**] As described above, when liquid crystal domains in each of which the liquid crystal molecules **30***a* take a radially-inclined orientation are arranged in a square lattice pattern across the entire picture element region, the existence probabilities of the liquid crystal molecules **30***a* of the respective axial orientations have rotational symmetry, whereby it is possible to realize a high-quality display without non-uniformity for any viewing angle. In order to reduce the viewing angle dependence of a liquid crystal domain having a radially-inclined orientation, the liquid crystal domain preferably has a high degree of rotational symmetry (preferably with at least a two-fold rotation axis, and more preferably with at least a four-fold rotation axis). Moreover, in order to reduce the viewing angle dependence across the entire picture element region, the plurality of liquid crystal domains provided in the picture element region are preferably arranged in a pattern (e.g., a square lattice pattern) which is a combination of a plurality of unit patterns (e.g., unit lattice patterns) each having a high degree of rotational symmetry (preferably with at least a two-fold rotation axis, and more preferably with at least a four-fold rotation axis).

[**0219**] **FIG. 15A** illustrates an example in which each opening **14***a* has a generally star shape and each unit solid portion **14***b*'has a generally circular shape, wherein such openings **14***a* and such unit solid portions **14***b*'are arranged in a square lattice pattern. However, the shape of the opening **14***a,* the shape of the unit solid portion **14***b',* and the arrangement thereof are not limited to those of the example above.

[**0220**] **FIG. 17**A and **FIG. 17B** are plan views respectively illustrating upper conductive layers **14**A and **14**B having respective openings **14***a* and unit solid portions **14***b*'of different shapes.

[**0221**] The openings **14***a* and the unit solid portions **14***b*'of the upper conductive layers **14**A and **14**B illustrated in **FIG. 17**A and **FIG. 17**B, respectively, are slightly distorted from those of the picture element electrode illustrated in **FIG. 15A**. The openings **14***a* and the unit solid portions **14***b*'of the upper conductive layers **14**A and **14**B have a two-fold rotation axis (not a four-fold rotation axis) and are regularly arranged so as to form oblong rectangular unit lattices. In both of the upper conductive layers **14**A and **14**B, the opening **14***a* has a distorted star shape, and the unit solid portion **14***b*'has a generally elliptical shape (a distorted circle). Also with the upper conductive layers **14**A and **14**B, it is possible to obtain a liquid crystal display device having a high display quality and a desirable viewing angle characteristic.

[**0222**] Moreover, upper conductive layers **14**C and **14**D as illustrated in **FIG. 18**A and **FIG. 18**B, respectively, may alternatively be used.

[0223] In the upper conductive layers **14**C and **14**D, generally cross-shaped openings **14***a* are arranged in a square lattice pattern so that each unit solid portion **14***b'*has a generally square shape. Of course, the patterns of the upper conductive layers **14**C and **14**D may be distorted so that there are oblong rectangular unit lattices. As described above, it is possible to obtain a liquid crystal display device having a high display quality and a desirable viewing angle characteristic alternatively by regularly arranging the generally rectangular (including a square and oblong rectangle) unit solid portions **14***b'*.

[0224] However, the shape of the opening **14***a* and/or the unit solid portion **14***b'*is preferably a circle or an ellipse, rather than a rectangle, so that a radially-inclined orientation is more stable. It is believed that a radially-inclined orientation is more stable with a circular or elliptical opening and/or unit solid portion because the edge of the opening **14***a* is more continuous (smooth), whereby the orientation direction of the liquid crystal molecules **30***a* changes more continuously (smoothly).

[0225] In view of the continuity of the orientation direction of the liquid crystal molecules **30***a* described above, upper conductive layers **14**E and **14**F as illustrated in **FIG. 19**A and **FIG. 19**B, respectively, are also desirable. The upper conductive layer **14**E illustrated in **FIG. 19A** is a variation of the upper conductive layer **14** illustrated in **FIG. 15A** in which each opening **14***a* is simply comprised of four arcs. The upper conductive layer **14**F illustrated in **FIG. 19B** is a variation of the upper conductive layer **14**D illustrated in **FIG. 18B** in which each unit solid portion **14***b'*defined by the surrounding openings **14***a* is formed by a combination of quarter arcs. In both of the upper conductive layers **14**E and **14**F, the openings **14***a* and the unit solid portions **14***b'*have a four-fold rotation axis and are arranged in a square lattice pattern (having a four-fold rotation axis). Alternatively, the shape of the unit solid portion **14***b'*of the opening **14***a* may be distorted into a shape having a two-fold rotation axis and arranged so as to form oblong rectangular lattices (having a two-fold rotation axis), as illustrated in **FIG. 17**A and **FIG. 17B**.

[0226] In the examples described above, the openings **14***a* are generally star-shaped or generally cross-shaped, and the unit solid portions **14***b'*are generally circular, generally elliptical, generally square (rectangular), and generally rectangular with rounded corners. Alternatively, the negative-positive relationship between the openings **14***a* and the unit solid portions **14***b'*may be inverted (hereinafter, the inversion of the negative-positive relationship between the openings **14***a* and the unit solid portions **14***b'*will be referred to simply as "inversion"). For example, **FIG. 20** illustrates an upper conductive layer **14**G having a pattern obtained by inverting the negative-positive relationship between the openings **14***a* and the unit solid portions **14***b'*of the upper conductive layer **14** illustrated in **FIG. 15A**. The upper conductive layer **14**G having an inverted pattern has substantially the same function as that of the upper conductive layer **14** illustrated in **FIG. 15A**. When the opening **14***a* and the unit solid portion **14***b'*both have a generally square shape, as in upper conductive layers **14**H and **14**I illustrated in **FIG. 21**A and **FIG. 21**B, respectively, the inverted pattern is substantially the same as the original pattern.

[0227] Also when the pattern illustrated in **FIG. 15A** is inverted as in the pattern illustrated in **FIG. 20**, it is preferred to form partial pieces (generally half or quarter pieces) of the opening **14***a* so as to form the unit solid portions **14***b'*having rotational symmetry at the edge portion of the upper conductive layer **14**. By employing such a pattern, the effect of an inclined electric field can be obtained at the edge portion of a picture element region as in the central portion of the picture element region, whereby it is possible to realize a stable radially-inclined orientation across the entire picture element region.

[0228] Next, which one of two inverted patterns should be employed will be discussed with respect to the upper conductive layer **14** of **FIG. 15**A and the upper conductive layer **14**G illustrated in **FIG. 20** having a pattern obtained by inverting the pattern of the openings **14***a* and the unit solid portions **14***b'*of the upper conductive layer **14**.

[0229] With either pattern, the length of the perimeter of each opening **14***a* is the same. Therefore, for the function of producing an inclined electric field, there is no difference between the two patterns. However, the area ratio of the unit solid portion **14***b'*(with respect to the total area of the upper conductive layer **14**) may differ between the two patterns. In other words, the area of the solid portion **14***b* (the portion where the conductive film exists) for producing an electric field which is applied through the liquid crystal molecules of the liquid crystal layer may differ therebetween.

[0230] The voltage applied through a liquid crystal domain formed in the opening **14***a* is lower than the voltage applied through another liquid crystal domain formed in the solid portion **14***b*. As a result, in a normally black mode display, for example, the liquid crystal domain formed in the opening **14***a* appears darker. Thus, as the area ratio of the openings **14***a* increases, the display brightness decreases. Therefore, it is preferred that the area ratio of the solid portion **14***b* is high. While the description herein ignores the effect of the lower conductive layer for the sake of simplicity, the two-layer electrode of the liquid crystal display device of the present invention includes a lower conductive layer (e.g., the lower conductive layer **12** of **FIG. 1A** to **FIG. 1C**) in a region corresponding to the opening **14***a* of the upper conductive layer **14**. Therefore, since an electric field from the lower conductive layer acts also upon the liquid crystal layer **30** in the region corresponding to the opening **14***a*, the degree of decrease in the display brightness along with an increase in the area ratio of the openings **14***a* is less than that for the conventional liquid crystal display device **300** described above with reference to **FIG. 4A** to **FIG. 4C**.

[0231] Whether the area ratio of the solid portion **14***b* is higher in the pattern of **FIG. 15A** or in the pattern of **FIG. 20** depends upon the pitch (size) of the unit lattice.

[0232] **FIG. 22A** illustrates a unit lattice of the pattern illustrated in **FIG. 15**A, and **FIG. 22B** illustrates a unit lattice of the pattern illustrated in **FIG. 20** (the opening **14***a* being taken as the center of each lattice). The portions illustrated in **FIG. 20** which serve to connect adjacent unit solid portions **14***b'*together (the branch portions extending in four directions from the circular portion) are omitted in **FIG. 22B**. The length of one side of the square unit lattice (the pitch) is denoted by "p", and the distance between the opening **14***a* or the unit solid portion **14***b'*and a side of the unit lattice (the width of the side space) is denoted by "s". It should be noted that at least one branch portion is sufficient to connect the unit solid portions **14***b'*with each other so as to set the unit solid portions **14***b*'at the same voltage. In general, boundary portions between the openings **14***a* or boundary portions between the unit solid portions **14***b*'may be in the form of the solid portion **14***b* or the opening **14***a* so long as the boundary portions do not affect the orientation of the liquid crystal molecules adversely.

[**0233**] Various samples of upper conductive layers **14** having different pitches p and side spaces s were produced so as to examine the stability of the radially-inclined orientation, etc. As a result, it was found that with the upper conductive layer **14** having a pattern illustrated in **FIG. 22A** (hereinafter, referred to as the "positive pattern"), the side space s needs to be about 2.75 μm or more so as to produce an inclined electric field required to obtain a radially-inclined orientation. It was found that with the upper conductive layer **14** having a pattern illustrated in **FIG. 22B** (hereinafter, referred to as the "negative pattern"), the side space s needs to be about2.25 μm or more so as to produce an inclined electric field required to obtain a radially-inclined orientation. For each pattern, the area ratio of the solid portion **14***b* was examined while changing the value of the pitch p with the side space s fixed to its lower limit value above. The results are shown in Table 1 below and in **FIG. 22C**.

TABLE 1

	Solid portion area ratio (%)	
Pitch p (μm)	Positive (FIG. 22A)	Negative (FIG. 22B)
20	41.3	52.9
25	47.8	47.2
30	52.4	43.3
35	55.8	40.4
40	58.4	38.2
45	60.5	36.4
50	62.2	35.0

[**0234**] As can be seen from Table 1 and **FIG. 22**C, the positive pattern (**FIG. 22A**) has a higher area ratio of the solid portion **14***b* when the pitch p is about 25 μm or more, and the negative pattern (**FIG. 22B**) has a higher area ratio of the solid portion **14***b* when the pitch p is less than about 25 μm. Therefore, in view of the display brightness and the stability of orientation, the pattern which should be employed changes at the critical pitch p of about 25 μm. For example, when three or fewer unit lattices are provided along the width direction of the upper conductive layer **14** having a width of 75 μm, the positive pattern illustrated in **FIG. 22A** is preferred, and when four or more unit lattices are provided, the negative pattern illustrated in **FIG. 22B** is preferred. For patterns other than that illustrated herein, the selection between a positive pattern and a negative pattern can similarly be made so as to obtain the larger area ratio of the solid portion **14***b*.

[**0235**] The number of unit lattices can be determined as follows. The various sizes for each unit lattice are calculated so that one or more (an integer number of) unit lattices are arranged along the width (horizontal or vertical) of the upper conductive layer **14**, and the area ratio of the solid portion is calculated for each calculated unit lattice size. Then, the unit lattice size such that the area ratio of the solid portion is maximized. Note that the orientation-regulating force from an inclined electric field decreases, whereby a stable radially-inclined orientation is not easily obtained, when the diameter of the unit solid portion **14***b*'(for the positive pattern) or the opening **14***a* (for the negative pattern) is less than 15 μm. The lower limit diameter value is for a case where the thickness of the liquid crystal layer **30** is about 3 μm. When the thickness of the liquid crystal layer **30** is less than about 3 μm, a stable radially-inclined orientation can be obtained even with a smaller diameter. When the thickness of the liquid crystal layer **30** is greater than about 3 μm, the lower limit diameter for obtaining a stable radially-inclined orientation is greater than the value shown above. In the liquid crystal display device of the present invention, since an electric field from the lower conductive layer also acts upon the liquid crystal layer **30**, the deterioration in the display quality can be suppressed even when the diameter of the opening **14***a* is set to be slightly greater than that shown in the above results.

[**0236**] Except that the picture element electrode **15** is a two-layer electrode having openings, the liquid crystal display device of Embodiment 1 described above may employ the same structure as that of a known vertical alignment type liquid crystal display device and can be produced by a known production method. A method for forming the two-layer picture element electrode will be described below and the description of the other steps of the production method will be omitted. Again, **FIG. 1**A, for example, will be referred to.

[**0237**] Up to the step of depositing a transparent conductive layer (typically, an ITO layer) which is to be the lower conductive layer **12**, a known method can be employed. Then, in the process of producing a known liquid crystal display device, the conductive layer is patterned into a predetermined pattern to provide a picture element electrode. The lower conductive layer **12** of the liquid crystal display device of the present embodiment can be patterned in the step of patterning the picture element electrode in the process of producing a known liquid crystal display device. The pattern of the lower conductive layer may be either the same as the picture element electrode or a divided pattern corresponding to the openings **14***a* in the upper conductive layer **14**. As in a conventional picture element electrode, the lower conductive layer **12** is electrically connected to the drain electrode, or the like, (an electrode substantially at the same potential as the drain) of a TFT.

[**0238**] The dielectric layer **13** is provided substantially across the entire surface of the substrate **100***a* on which the lower conductive layer **12** has been patterned. The dielectric layer **13** may be provided by using a transparent photosensitive resin, for example. Then, a conductive layer is deposited on the dielectric layer **13** again. The obtained conductive layer is patterned so as to provide the upper conductive layer **14** having the openings **14***a*.

[**0239**] Contact holes are provided in the dielectric layer **13** in advance for connecting the upper conductive layer **14** to TFT drain electrodes. This step can also be performed by using a known process. With a structure where the upper conductive layer **14** and the lower conductive layer **12** are driven at the same potential, the upper conductive layer **14** and the lower conductive layer **12** may be connected to the same TFT, as illustrated herein. This structure also provides an advantage that a conventional driving circuit can be employed as it is.

[0240] Typically, a vertical alignment layer (not shown) is provided on one side of each of the picture element electrode **15** and the counter electrode **22** which is closer to the liquid crystal layer **30** so as to vertically align the liquid crystal molecules having a negative dielectric anisotropy. The vertical alignment layer can be provided in the display region of the substrate **100***a* by a printing process after the provision of the upper conductive layer **14** having the openings **14***a*.

[0241] Herein, the liquid crystal material is a nematic liquid crystal material having a negative dielectric anisotropy. A guest-host mode liquid crystal display device can be obtained by adding a dichroic dye to a nematic liquid crystal material having a negative dielectric anisotropy. A guest-host mode liquid crystal display device does not require a polarizing plate.

EMBODIMENT 2

[0242] The structure of one picture element region of a liquid crystal display device **400**B according to Embodiment 2 of the present invention will now be described with reference to **FIG. 23**A and **FIG. 23B**. In the subsequent figures, each element having substantially the same function as that of the liquid crystal display device **400** illustrated in **FIG. 11A** to **FIG. 11C** will be denoted by the same reference numeral and will not be further described. **FIG. 23A** is a plan view as viewed in the substrate normal direction, and **FIG. 23B** is a cross-sectional view taken along line 23B-23B' of **FIG. 23A**. **FIG. 23B** schematically illustrates a state where no voltage is applied across the liquid crystal layer.

[0243] As illustrated in **FIG. 23**A and **FIG. 23**B, the liquid crystal display device **400**B is different from the liquid crystal display device **400**A of Embodiment 1 illustrated in **FIG. 15**A and **FIG. 15B** in that a TFT substrate **400***b* of the liquid crystal display device **400**B includes a protrusion **40** in the opening **14***a* of the upper conductive layer **14**. A vertical alignment film (not shown) is provided on the surface of the protrusion **40**. Hereinafter, the TFT substrate having the protrusion **40** in the opening **14***a* will be denoted by the reference numeral **400***b* regardless of the structure of the protrusion **40**.

[0244] While the liquid crystal display device **400**B obtained by providing the protrusion **40** in the opening **14***a* of the upper conductive layer **14** of the liquid crystal display device **400** illustrated in **FIG. 11A** to **FIG. 11C** is illustrated herein, the structure with the protrusion **40** can also be applied to other liquid crystal display devices of Embodiment 1.

[0245] The cross section of the protrusion **40** along the plane of the substrate **11** is a generally star-shaped cross section, i.e., the same shape as that of the opening **14***a,* as illustrated in **FIG. 23A**. Note that adjacent protrusions **40** are connected to each other so as to completely surround each unit solid portion **14***b'*in a generally circular pattern. The cross section of the protrusion **40** along a plane vertical to the substrate **11** is trapezoidal shape as illustrated in **FIG. 23B**. Specifically, the cross section has a top surface **40***t* parallel to the substrate plane and a side surface **40***s* inclined by a taper angle θ(<90°) with respect to the substrate plane. Since the vertical alignment film (not shown) is provided so as to cover the protrusion **40**, the side surface **40***s* of the protrusion **40** has an orientation-regulating force of the same direction as that of an inclined electric field for the liquid crystal molecules **30***a* of the liquid crystal layer **30**, thereby functioning to stabilize the radially-inclined orientation.

[0246] The function of the protrusion **40** will now be described with reference to **FIG. 24A** to **FIG. 24**D, **FIG. 25**A and **FIG. 25B**.

[0247] First, the relationship between the orientation of the liquid crystal molecules **30***a* and the configuration of the surface having a vertical alignment power will be described with reference to **FIG. 24A** to **FIG. 24D**.

[0248] As illustrated in **FIG. 24A, a** liquid crystal molecule **30***a* on a horizontal surface is aligned vertical to the surface due to the orientation-regulating force of the surface having a vertical alignment power (typically, the surface of a vertical alignment film). When an electric field represented by an equipotential line EQ perpendicular to the axial orientation of the liquid crystal molecule **30***a* is applied through the liquid crystal molecule **30***a* in a vertical alignment, a torque urging the liquid crystal molecule **30***a* to incline clockwise and a torque urging the liquid crystal molecule **30***a* to incline counterclockwise act upon the liquid crystal molecule **30***a* with the same probability. Therefore, in the liquid crystal layer **30** between a pair of opposing electrodes in a parallel plate arrangement include some liquid crystal molecules **30***a* which are subject to the clockwise torque and other liquid crystal molecules **30***a* which are subject to the counterclockwise torque. As a result, the transition to the orientation according to the voltage applied across the liquid crystal layer **30** may not proceed smoothly.

[0249] When an electric field represented by a horizontal equipotential line EQ is applied through a liquid crystal molecule **30***a* vertically aligned to an inclined surface, as illustrated in **FIG. 24**B, the liquid crystal molecule **30***a* inclines in whichever direction (the clockwise direction in the illustrated example) that requires less inclination for the liquid crystal molecule **30***a* to be parallel to the equipotential line EQ. Then, as illustrated in **FIG. 24**C, other adjacent liquid crystal molecules **30***a* aligned vertical to a horizontal surface incline in the same direction (the clockwise direction) as the liquid crystal molecule **30***a* located on the inclined surface so that the orientation thereof is continuous (in conformity) with the orientation of the liquid crystal molecule **30***a* aligned vertical to the inclined surface.

[0250] As illustrated in **FIG. 24**D, for a surface with concave/convex portions whose cross section includes a series of trapezoids, the liquid crystal molecules **30***a* on the top surface and those on the bottom surface are oriented so as to conform with the orientation direction regulated by other liquid crystal molecules **30***a* on the inclined portions of the surface.

[0251] In the liquid crystal display device of the present embodiment, the direction of the orientation-regulating force exerted by the configuration (protrusions) of the surface is aligned with the direction of the orientation-regulating force exerted by an inclined electric field, thereby stabilizing the radially-inclined orientation.

[0252] **FIG. 25**A and **FIG. 25B** each illustrate a state in the presence of an applied voltage across the liquid crystal layer **30** shown in **FIG. 23B**. **FIG. 25A** schematically illustrates a state where the orientation of the liquid crystal molecules **30***a* has just started to change (initial ON state) according to the voltage applied across the liquid crystal layer **30**. **FIG. 25B** schematically illustrates a state where the orientation of the liquid crystal molecules **30***a* which has changed and become steady according to the applied voltage. In **FIG.** 25A and **FIG.** 25B, curves EQ denote equipotential lines.

[**0253**] When the upper conductive layer **14**, the lower conductive layer **12** and the counter electrode **22** are at the same potential (i.e., in a state where no voltage is applied across the liquid crystal layer **30**), the liquid crystal molecules **30***a* in each picture element region are aligned vertical to the surfaces of the substrates **11** and **21** as illustrated in **FIG. 23B**. The liquid crystal molecules **30***a* in contact with the vertical alignment film (not shown) on the side surface **40***s* of the protrusion **40** are aligned vertical to the side surface **40***s*, and the liquid crystal molecules **30***a* in the vicinity of the side surface **40***s* take an inclined orientation as illustrated due to the interaction (the nature as an elastic continuum) with the surrounding liquid crystal molecules **30***a*.

[**0254**] When a voltage is applied across the liquid crystal layer **30**, a potential gradient represented by equipotential lines EQ shown in **FIG. 25A** is produced. The equipotential lines EQ are parallel to the surfaces of the solid portion **14***b* and the counter electrode **22** in a region of the liquid crystal layer **30** located between the solid portion **14***b* of the upper conductive layer **14** and the counter electrode **22**, and drop in a region corresponding to the opening **14***a* of the upper conductive layer **14**, thereby producing an inclined electric field represented by the inclined portion of the equipotential lines EQ in each region of the liquid crystal layer **30** above an edge portion (the peripheral portion of and within the opening **14***a* including the boundary thereof) EG of the opening **14***a*. An electric field represented by equipotential lines EQ parallel to the surfaces of the lower conductive layer **12** and the counter electrode **22** is produced in a portion of the region of the liquid crystal layer **30** corresponding to the opening **14***a* of the upper conductive layer **14** where the liquid crystal molecules **30***a* are not influenced by the potential of the upper conductive layer **14**.

[**0255**] Due to the inclined electric field, the liquid crystal molecules **30***a* above the right edge portion EG in **FIG. 25A** incline (rotate) clockwise and the liquid crystal molecules **30***a* above the left edge portion EG incline (rotate) counterclockwise as indicated by arrows in **FIG.** 25A, as described above, so as to be parallel to the equipotential lines EQ. The direction of the orientation-regulating force exerted by the inclined electric field is the same as that of the orientation-regulating force exerted by the side surface **40***s* located at each edge portion EG.

[**0256**] As described above, the change in the orientation starts from the liquid crystal molecules **30***a* located on the inclined portion of the equipotential lines EQ, and reaches a steady state of the orientation schematically illustrated in **FIG. 25B**. The liquid crystal molecules **30***a* around the central portion of the top surface **40***t* of the protrusion **40** are substantially equally influenced by the respective orientations of the liquid crystal molecules **30***a* at the opposing edge portions EG of the opening **14***a*, and therefore retain their orientation perpendicular to the equipotential lines EQ. The liquid crystal molecules **30***a* away from the center of the opening **14***a* (the top surface **40***t* of the protrusion **40**) incline by the influence of the orientation of other liquid crystal molecules **30***a* at the closer edge portion EG, thereby forming an inclined orientation which is symmetric about the center SA of the opening **14***a* (the top surface **40***t* of the protrusion **40**). An inclined orientation symmetric about the center SA of the unit solid portion **14***b'*is formed also in the region corresponding to the unit solid portion **14***b'*which is substantially surrounded by the openings **14***a* and the protrusions **40**.

[**0257**] As described above, in the liquid crystal display device **400**B of Embodiment 2, as in the liquid crystal display device **400**A of Embodiment 1, liquid crystal domains each having a radially-inclined orientation are formed corresponding to the openings **14***a* and the unit solid portions **14***b'*(see **FIG. 16C**). Since the protrusions **40** are provided so as to completely surround each unit solid portion **14***b'*in a generally circular pattern, each liquid crystal domain is formed corresponding the generally circular region surrounded by the protrusions **40**. Since the side surface **40***s* of the protrusion **40** provided in the opening **14***a* functions to incline the liquid crystal molecules **30***a* in the vicinity of the edge portion EG of the opening **14***a* in the same direction as the direction of the orientation-regulating force exerted by the inclined electric field, thereby stabilizing the radially-inclined orientation.

[**0258**] Of course, the orientation-regulating force exerted by the inclined electric field only acts in the presence of an applied voltage, and the strength thereof depends upon the strength of the electric field (the level of the applied voltage). Therefore, when the electric field strength is small (i.e., when the applied voltage is low), the orientation-regulating force exerted by the inclined electric field is weak, in which case the radially-inclined orientation may collapse due to floating of the liquid crystal material when an external force is applied to the liquid crystal panel. Once the radially-inclined orientation collapses, it is not restored until application of a voltage sufficient to produce an inclined electric field which exerts a sufficiently strong orientation-regulating force. On the other hand, the orientation-regulating force from the side surface **40***s* of the protrusion **40** is exerted regardless of the applied voltage, and is very strong as it is known in the art as the "anchoring effect" of the alignment film. Therefore, even when floating of the liquid crystal material occurs and the radially-inclined orientation once collapses, the liquid crystal molecules **30***a* in the vicinity of the side surface **40***s* of the protrusion **40** retain the same orientation direction as that of the radially-inclined orientation. Therefore, the radially-inclined orientation is easily restored once the floating of the liquid crystal material stops.

[**0259**] Thus, the liquid crystal display device **400**B of Embodiment 2 has an additional advantage of being strong against an external force in addition to the advantages of the liquid crystal display device **400**A of Embodiment 1. Therefore, the liquid crystal display device **400**B can be suitably used in apparatuses which are often subject to an external force, such as PCs which are often carried around and PDAs.

[**0260**] When the protrusion **40** is made of a dielectric material having a high transparency, there is obtained an advantage of improving the contribution to the display of a liquid crystal domain which is formed in a region corresponding to the opening **14***a*. When the protrusion **40** is made of an opaque dielectric material, there is obtained an advantage that it is possible to prevent light leakage caused by the retardation of the liquid crystal molecules **30***a* which are in an inclined orientation due to the side surface **40***s* of the protrusion **40**. Whether to employ a transparent dielectric material or an opaque dielectric material can be determined in view of the application of the liquid crystal display device. In either case, the use of a photosensitive resin provides an advantage that the step of patterning the protrusions **40** corresponding to the openings **14***a* can be simplified. In order to obtain a sufficient orientation-regulating force, the height of the protrusion **40** is preferably in the range of about 0.5 μm to about 2 μm, when the thickness of the liquid crystal layer **30** is about 3 μm. Typically, the height of the protrusion **40** is preferably in the range of about ⅙ to about ⅔ of the thickness of the liquid crystal layer **30**.

[0261] As described above, the liquid crystal display device **400B** includes the protrusion **40** in the opening **14***a* of the upper conductive layer **14**, and the side surface **40***s* of the protrusion **40** exerts an orientation-regulating force in the same direction as that of the orientation-regulating force exerted by an inclined electric field for the liquid crystal molecules **30***a* of the liquid crystal layer **30**. Preferred conditions for the side surface **40***s* to exert an orientation-regulating force of the same direction as that of the orientation-regulating force exerted by the inclined electric field will now be described with reference to **FIG. 26A** to **FIG. 26C**.

[0262] **FIG. 26A** to **FIG. 26C** schematically illustrate cross-sectional views of liquid crystal display devices **400C**, **400D** and **400E**, respectively. **FIG. 26A** to **FIG. 26C** correspond to **FIG. 25A**. The liquid crystal display devices **400C**, **400D** and **400E** all have a protrusion at least in the opening **14***a*, but differ from the liquid crystal display device **400B** in terms of the positional relationship between the entire protrusion **40** as a single structure and the corresponding opening **14***a*.

[0263] In the liquid crystal display device **400B** described above, the entire protrusion **40** as a structure is formed in the opening **14***a*, and the bottom surface of the protrusion **40** is smaller than the opening **14***a*, as illustrated in **FIG. 25A**. In the liquid crystal display device **400C** illustrated in **FIG. 26A**, the bottom surface of a protrusion **40A** is aligned with the opening **14***a*. In the liquid crystal display device **400D** illustrated in **FIG. 26B**, the bottom surface of the protrusion **40B** is greater than the opening **14***a* so as to cover a portion of the solid portion (conductive film) **14***b* surrounding the opening **14***a*. The solid portion **14***b* is not formed on the side surface **40***s* of any of the protrusions **40**, **40A** and **40B**. As a result, the equipotential lines EQ are substantially flat over the solid portion **14***b* and drop into the opening **14***a*, as illustrated in the respective figures. Therefore, as the protrusion **40** of the liquid crystal display device **400B**, the side surface **40***s* of the protrusion **40A** of the liquid crystal display device **400C** and that of the protrusion **40B** of the liquid crystal display device **400D** both exert an orientation-regulating force of the same direction as that of the orientation-regulating force exerted by the inclined electric field, thereby stabilizing the radially-inclined orientation.

[0264] In contrast, in the liquid crystal display device **400E** illustrated in **FIG. 26C**, the bottom surface of a protrusion **40C** is greater than the opening **14***a*, and a portion of the solid portion **14***b* extending into a region above the opening **14***a* is formed on the side surface **40***s* of the protrusion **40C**. Due to the influence of the portion of the solid portion **14***b* formed on the side surface **40***s*, a ridge portion is created in the equipotential lines EQ. The ridge portion of the equipotential lines EQ has a gradient opposite to that of the other portion of the equipotential lines EQ dropping into the opening **14***a*. This indicates that an inclined electric field has been produced whose direction is opposite to that of an inclined electric field for orienting the liquid crystal molecules **30***a* into a radially-inclined orientation. Therefore, in order for the side surface **40***s* to have an orientation-regulating force of the same direction as that of the orientation-regulating force exerted by the inclined electric field, it is preferred that the solid portion (conductive film) **14***b* is not formed on the side surface **40***s*.

[0265] Next, a cross-sectional structure of the protrusion **40** taken along line 27A-27A' of **FIG. 23A** will be described with reference to **FIG. 27**.

[0266] Since the protrusions **40** illustrated in **FIG. 23A** are formed so as to completely surround each unit solid portion **14***b*'in a generally circular pattern, as described above, the portions serving to connect adjacent unit solid portions **14***b* together (the branch portions extending in four directions from the circular portion) are formed on the protrusion **40** as illustrated in **FIG. 27**. Therefore, in the step of depositing the conductive film to be the solid portions **14***b* of the upper conductive layer **14**, there is a considerable possibility that disconnection may occur on the protrusion **40** or delamination may occur in an after-treatment of the production process.

[0267] In view of this, in a liquid crystal display device **400F** illustrated in **FIG. 28A** and **FIG. 28B**, protrusions **40D** independent of one another are formed so that each of the protrusions **40D** is completely included within the opening **14***a* so that the conductive film to be the solid portion **14***b* is formed on the flat surface of the substrate **11**, thereby eliminating the possibility of disconnection or delamination. Although the protrusions **40D** do not completely surround each unit solid portion **14***b*'in a generally circular pattern, a generally circular liquid crystal domain corresponding to each unit solid portion **14***b*'is formed, and the radially-inclined orientation of the unit solid portion **14***b*'is stabilized as in the above-described examples.

[0268] The effect of stabilizing the radially-inclined orientation which is obtained by forming the protrusion **40** in the opening **14***a* is not limited to the pattern of the opening **14***a* described above, but may similarly be applied to any pattern of the opening **14***a* described above in Embodiment 1 to obtain effects as those described above. In order for the protrusion **40** to sufficiently exert the effect of stabilizing the orientation against an external force, it is preferred that the pattern of the protrusion **40** (the pattern as viewed in the substrate normal direction) covers as much area as possible of the liquid crystal layer **30**. Therefore, for example, a greater orientation stabilizing effect of the protrusion **40** can be obtained with the positive pattern with circular unit solid portions **14***b*'than with the negative pattern with circular openings **14***a*.

EMBODIMENT 3

[0269] In the liquid crystal display device of Embodiment 1 described above, a two-layer electrode is employed for one (the picture element electrode **15** in the illustrated example) of the picture element electrode **15** defining picture element regions and the counter electrode **22** opposing each other via the liquid crystal layer **30**, and the openings **14***a* are provided in the upper conductive layer **14**, so that an inclined electric field is produced in the presence of an applied voltage, thereby orienting the liquid crystal molecules into a radially-inclined orientation by using the inclined electric field. In the liquid crystal display device of Embodiment 2, the protrusion is provided in the opening **14***a* of the upper conductive layer **14** so as to stabilize the radially-inclined orientation.

[**0270**] Embodiment 3 is a liquid crystal display device including a further orientation-regulating structure provided on the substrate (the counter substrate in the examples described above) which is different from the substrate on which the two-layer electrode is provided (the TFT substrate in the examples described above). In the following description, an electrode structure for realizing a radially-inclined orientation by the above-described inclined electric field will be referred to as the first orientation-regulating structure, and a further orientation-regulating structure provided on the other side of the liquid crystal layer with respect to the first orientation-regulating structure will be referred to as the second orientation-regulating structure.

[**0271**] Next, the specific structure and function of the second orientation-regulating structure will be described. A case where the first orientation-regulating structure is provided on the TFT substrate and the second orientation-regulating structure is provided on the counter substrate will be described below in conformity with the examples illustrated above.

[**0272**] **FIG. 29A** to **FIG. 29E** schematically illustrate a counter substrate **200***b* having a second orientation-regulating structure **28**. Each element having substantially the same function as that of the liquid crystal display devices described above will be denoted by the same reference numeral and will not be further described.

[**0273**] The second orientation-regulating structure **28** illustrated in **FIG. 29A** to **FIG. 29E** functions to orient the liquid crystal molecules **30***a* of the liquid crystal layer **30** into a radially-inclined orientation. Note that the second orientation-regulating structure **28** illustrated in **FIG. 29A** to **FIG. 29**D and that illustrated in **FIG. 29E** are different in terms of the direction in which the liquid crystal molecules **30***a* are to be inclined.

[**0274**] The direction in which the liquid crystal molecules are inclined by the second orientation-regulating structure **28** illustrated in **FIG. 29A** to **FIG. 29D** is aligned with the orientation direction of the radially-inclined orientation of each liquid crystal domain which is formed by the first orientation-regulating structure in a region corresponding to the unit solid portion **14***b*'(see, for example, **FIG. 11C**) of the upper conductive layer **14**. In contrast, the direction in which the liquid crystal molecules are inclined by the second orientation-regulating structure **28** illustrated in **FIG. 29E** is aligned with the orientation direction of the radially-inclined orientation of each liquid crystal domain which is formed by the first orientation-regulating structure in a region corresponding to the opening **14***a* (see, for example, **FIG. 11C**) of the upper conductive layer **14**.

[**0275**] The second orientation-regulating structure **28** illustrated in **FIG. 29A** is formed by an opening **22***a* of the counter electrode **22** which is provided so as to oppose the upper conductive layer **14** (e.g., the unit solid portion **14***b*'of **FIG. 15A**). A vertical alignment film (not shown) is provided on one surface of the counter substrate **200***b* which is closer to the liquid crystal layer **30**.

[**0276**] The second orientation-regulating structure **28**, as the first orientation-regulating structure described above, exerts an orientation-regulating force only in the presence of an applied voltage. Since the second orientation-regulating structure **28** is only required to exert an orientation-regulating force upon the liquid crystal molecules in each liquid crystal domain in a radially-inclined orientation formed by the first orientation-regulating structure, the size of the opening **22***a* is smaller than the opening **14***a* provided in the upper conductive layer **14**, and smaller than the unit solid portion **14***b*'(see, for example, **FIG. 15A**) which is surrounded by the openings **14***a*. For example, a sufficient effect can be obtained only with an area less than or equal to one half of that of the opening **14***a* or the unit solid portion **14***b*'. When the opening **22***a* of the counter electrode **22** is provided so as to oppose the central portion of the unit solid portion **14***b*'of the upper conductive layer **14**, the continuity of the orientation of the liquid crystal molecules increases, and it is possible to fix the position of the central axis of the radially-inclined orientation.

[**0277**] As described above, when a structure exerting an orientation-regulating force only in the presence of an applied voltage is employed as the second orientation-regulating structure, substantially all of the liquid crystal molecules **30***a* of the liquid crystal layer **30** take a vertical alignment in the absence of an applied voltage. Therefore, when employing a normally black mode, substantially no light leakage occurs in a black display, thereby realizing a display with a desirable contrast ratio.

[**0278**] However, in the absence of an applied voltage, the orientation-regulating force is not exerted and thus the radially-inclined orientation is not formed. Moreover, when the applied voltage is low, there is only a weak orientation-regulating force, whereby an after image may be observed when a considerable stress is applied upon the liquid crystal panel.

[**0279**] Each of the second orientation-regulating structures **28** illustrated in **FIG. 29B** to **FIG. 29D** exerts an orientation-regulating force regardless of the presence/absence of an applied voltage, whereby it is possible to obtain a stable radially-inclined orientation at any display gray level, and there is provided a high resistance to a stress.

[**0280**] First, the second orientation-regulating structure **28** illustrated in **FIG. 29B** includes a protrusion **22***b* which is provided on the counter electrode **22** so as to protrude into the liquid crystal layer **30**. While there is no particular limitation on the material of the protrusion **22***b*, the protrusion **22***b* can be easily provided by using a dielectric material such as a resin. A vertical alignment film (not shown) is provided on one surface of the counter substrate **200***b* which is closer to the liquid crystal layer **30**. The protrusion **22***b* orients the liquid crystal molecules **30***a* into a radially-inclined orientation by virtue of the configuration of the surface thereof (with a vertical alignment power). It is preferred to use a resin material which deforms by heat, in which case it is possible to easily form the protrusion **22***b* having a slightly-humped cross section as illustrated in **FIG.**

29B through a heat treatment after patterning. The protrusion **22***b* having a slightly-humped cross section with a vertex (e.g., a portion of a sphere) as illustrated in the figure or a conical protrusion provides a desirable effect of fixing the central position of the radially-inclined orientation.

[**0281**] The second orientation-regulating structure **28** illustrated in **FIG. 29C** is provided as a surface having a horizontal alignment power facing the liquid crystal layer **30** which is provided in an opening (or a depressed portion) **23***a* in a dielectric layer **23** formed under the counter electrode **22** (i.e., on one side of the counter electrode **22** which is closer to the substrate **21**). A vertical alignment film **24** is provided so as to cover one side of the counter substrate **200***b* which is closer to the liquid crystal layer **30** while leaving a region corresponding to the opening **23***a* uncovered, whereby the surface in the opening **23***a* functions as a horizontal alignment surface. Alternatively, a horizontal alignment film **25** may be provided only in the opening **23***a* as illustrated in **FIG. 29D**.

[**0282**] The horizontal alignment film illustrated in **FIG. 29D** can be provided by, for example, once providing the vertical alignment film **24** across the entire surface of the counter substrate **200***b,* and then selectively irradiating a portion of the vertical alignment film **24** in the opening **23***a* with UV Light so as to reduce the vertical alignment power thereof. The horizontal orientation power required for the second orientation-regulating structure **28** does not have to be so high that the resulting pretilt angle is as small as that resulting from an alignment film used in a TN type liquid crystal display device. For example, a pretilt angle of 45° or less is sufficient.

[**0283**] As illustrated in **FIG.** 29C and **FIG.** 29D, on the horizontal orientation surface in the opening **23***a,* the liquid crystal molecules **30***a* are urged to be horizontal with respect to the substrate plane. As a result, the liquid crystal molecules **30***a* form an orientation which is continuous with the orientation of the surrounding, vertically aligned liquid crystal molecules **30***a* on the vertical alignment film **24**, thereby obtaining a radially-inclined orientation as illustrated in the figure.

[**0284**] A radially-inclined orientation can be obtained only by selectively providing a horizontal orientation surface (e.g., the surface of the electrode, or a horizontal alignment film) on the flat surface of the counter electrode **22** without providing a depressed portion (which is formed by the opening in the dielectric layer **23**) on the surface of the counter electrode **22**. However, the radially-inclined orientation can be further stabilized by virtue of the surface configuration of the depressed portion.

[**0285**] It is preferred to use a color filter layer or an overcoat layer of a color filter layer as the dielectric layer **23**, for example, to form the depressed portion in the surface of the counter substrate **200***b* which is closer to the liquid crystal layer **30**, because it adds nothing to the process. In the structures illustrated in **FIG.** 29C and **FIG.** 29D, there is little decrease in light efficiency because there is no region where a voltage is applied across the liquid crystal layer **30** via the protrusion **22***b* as in the structure illustrated in **FIG. 29A**.

[**0286**] In the second orientation-regulating structure **28** illustrated in **FIG. 29E, a** depressed portion is formed on one side of the counter substrate **200***b* which is closer to the liquid crystal layer **30** by using the opening **23***a* of the dielectric layer **23**, as in the second orientation-regulating structure **28** illustrated in **FIG.** 29D, and a horizontal alignment film **26** is formed only in the bottom portion of the depressed portion. Instead of forming the horizontal alignment film **26**, the surface of the counter electrode **22** may be exposed as illustrated in **FIG.** 29C.

[**0287**] A liquid crystal display device **400**G having the first orientation-regulating structure and the second orientation-regulating structure as described above is shown in **FIG. 30**A and **FIG. 30B**. **FIG. 30A** is a plan view, and **FIG. 30B** is a cross-sectional view taken along line 22B-22B' of **FIG. 30A**.

[**0288**] The liquid crystal display device **400**G includes the TFT substrate **400***a* having the upper conductive layer **14** with the openings **14***a* which includes the first orientation-regulating structure, and the counter substrate **200***b* which includes the second orientation-regulating structure **28**. The first orientation-regulating structure is not limited to the structure illustrated herein, but may be any other structure described above. A structure which exerts an orientation-regulating force even in the absence of an applied voltage (**FIG. 29B** to **FIG. 29D** and **FIG. 29E**) will be illustrated as the second orientation-regulating structure **28**. Note that the first orientation-regulating structure illustrated in **FIG. 29B** to **FIG. 29D** can be replaced with that illustrated in **FIG. 29A**.

[**0289**] Among the second orientation-regulating structures **28** provided in the counter substrate **200***b* of the liquid crystal display device **400**G, the second orientation-regulating structure **28** provided around the center of a region opposing the solid portion **14***b* of the upper conductive layer **14** is one of those illustrated in **FIG. 29B** to **FIG.** 29D, and the second orientation-regulating structure **28** provided around the center of a region opposing the opening **14***a* of the upper conductive layer **14** is one illustrated in **FIG. 29E**.

[**0290**] With such an arrangement, in the presence of an applied voltage across the liquid crystal layer **30**, i.e., in the presence of an applied voltage between the upper conductive layer **14** and the counter electrode **22**, the direction of the radially-inclined orientation formed by the first orientation-regulating structure is aligned with the direction of the radially-inclined orientation formed by the second orientation-regulating structure **28**, thereby stabilizing the radially-inclined orientation. This is schematically shown in **FIG. 30A** to **FIG. 30C**. **FIG. 30A** illustrates a state in the absence of an applied voltage, **FIG. 30B** illustrates a state where the orientation has just started to change (initial ON state) after application of a voltage, and **FIG. 30C** schematically illustrates a steady state during the voltage application.

[**0291**] As illustrated in **FIG.** 31A, the orientation-regulating force exerted by the second orientation-regulating structure (**FIG. 29B** to **FIG. 29D**) acts upon the liquid crystal molecules **30***a* in the vicinity thereof even in the absence of an applied voltage, thereby forming a radially-inclined orientation.

[**0292**] When voltage application begins, an electric field represented by equipotential lines EQ shown in **FIG. 31B** is produced (by the first orientation-regulating structure), and a liquid crystal domain in which the liquid crystal molecules

30*a* are in a radially-inclined orientation is formed in each region corresponding to the opening **14***a* and each region corresponding to the solid portion **14***b,* and the liquid crystal layer **30** reaches a steady state as illustrated in **FIG. 31C**. The inclination direction of the liquid crystal molecules **30***a* in each liquid crystal domain coincides with the direction in which the liquid crystal molecules **30***a* are inclined by the orientation-regulating force exerted by the second orientation-regulating structure **28** which is provided in a corresponding region.

[**0293**] When a stress is applied upon the liquid crystal display device **400**G which is in a steady state, the radially-inclined orientation of the liquid crystal layer **30** once collapses, but upon removal of the stress, the radially-inclined orientation is restored because of the orientation-regulating forces from the first orientation-regulating structure and the second orientation-regulating structure acting upon the liquid crystal molecules **30***a*. Therefore, the occurrence of an after image due to a stress is suppressed. When the orientation-regulating force from the second orientation-regulating structure **28** is excessively strong, retardation occurs even in the absence of an applied voltage due to the radially-inclined orientation, whereby the display contrast ratio may decrease. However, the orientation-regulating force from the second orientation-regulating structure **28** does not have to be strong because it is only required to have an effect of stabilizing a radially-inclined orientation formed by the first orientation-regulating structure and fixing the central axis position thereof. Therefore, an orientation-regulating force which would not cause such a degree of retardation as to deteriorate the display quality is sufficient.

[**0294**] For example, when the protrusion **22***b* illustrated in **FIG. 29B** is employed, each protrusion **22***b* may have a diameter of about 15 μm and a height (thickness) of about 1 μm for the unit solid portion **14***b'* having a diameter of about 30 μm to about 35 μm, thereby obtaining a sufficient orientation-regulating force and suppressing the reduction in the contrast ratio due to retardation to a practical level.

[**0295**] **FIG. 32**A and **FIG. 32B** illustrate another liquid crystal display device **400**H including the first orientation-regulating structure and the second orientation-regulating structure. **FIG. 32A** is a plan view, and **FIG. 32B** is a cross-sectional view taken along line **32**B-**32**B' of **FIG. 32A**.

[**0296**] The liquid crystal display device **400**H does not have the second orientation-regulating structure in a region opposing the opening **14***a* of the upper conductive layer **14** of the TFT substrate **400***a*. Formation of the second orientation-regulating structure **28** illustrated in **FIG. 29E** which should be formed in a region opposing the opening **14***a* introduces difficulties into the process. Therefore, in view of the productivity, it is preferred to use only one of the second orientation-regulating structures **28** illustrated in **FIG. 29A** to **FIG. 29D**. Particularly, the second orientation-regulating structure **28** illustrated in **FIG. 29B** is preferred because it can be produced by a simple process.

[**0297**] Even if no second orientation-regulating structure is provided in a region corresponding to the opening **14***a* as in the liquid crystal display device **400**H, a radially-inclined orientation as that of the liquid crystal display device **400G** is obtained, as schematically illustrated in **FIG. 33A** to **FIG. 33**C, and also the stress resistance thereof is at a practical level.

EMBODIMENT 4

[**0298**] In the liquid crystal display device of the present embodiment, the dielectric layer provided between the upper conductive layer and the lower conductive layer of the picture element electrode includes an opening (aperture) or a depressed portion in the opening of the upper conductive layer. In other words, in the two-layer picture element electrode of the liquid crystal display device of the present embodiment, the whole of a region of the dielectric layer located in the opening of the upper conductive layer is removed (thereby forming a opening therein) or a portion of such a region is removed (thereby forming a depressed portion).

[**0299**] First, the structure and operation of a liquid crystal display device **500** having such a picture element electrode which includes a opening in the dielectric layer will be described with reference to **FIG. 34A** to **FIG. 34C**.

[**0300**] In the liquid crystal display device **500**, the upper conductive layer **14** of the picture element electrode **15** includes the opening **14***a,* and the dielectric layer **13** provided between the lower conductive layer **12** and the upper conductive layer **14** includes an opening **13***a* formed so as to correspond to the opening **14***a* of the upper conductive layer **14**, with the lower conductive layer **12** being exposed through the opening **13***a*. The side wall of the opening **14***a* of the dielectric layer **13** is typically tapered (taper angle: θ). The liquid crystal display device **500** has substantially the same structure as that of the liquid crystal display device **100** of Embodiment 1 except that the dielectric layer **13** includes the opening **13***a,* and the two-layer picture element electrode **15** functions in substantially the same manner as the picture element electrode **15** of the liquid crystal display device **100,** to orient the liquid crystal layer **30** into a radially-inclined orientation in the presence of an applied voltage.

[**0301**] The operation of the liquid crystal display device **500** will be described with reference to **FIG. 34A** to **FIG. 34C**. **FIG. 34A** to **FIG. 34C** respectively correspond to **FIG. 1A** to **FIG. 1C** illustrating the liquid crystal display device **100** of Embodiment 1.

[**0302**] As illustrated in **FIG. 34**A, the liquid crystal molecules **30***a* in each picture element region are aligned vertical to the surfaces of the substrates **11** and **21** in the absence of an applied voltage (OFF-state). In the following description, the orientation-regulating force from the side wall of the opening **13***a* will be ignored for the sake of simplicity.

[**0303**] When a voltage is applied across the liquid crystal layer **30**, a potential gradient represented by equipotential lines EQ shown in **FIG. 34B** is produced. As can be seen from the drop of the equipotential lines EQ (creating a "trough" therein) in a region corresponding to the opening **14***a* of the upper conductive layer **14**, an inclined electric field is produced in the liquid crystal layer **30** of the liquid crystal display device **500** as in the potential gradient illustrated in **FIG. 1B**. However, since the dielectric layer **13** of the picture element electrode **15** includes the opening **13***a* in a region corresponding to the opening **14***a* of the upper conductive layer **14,** the voltage applied across the region of the liquid crystal layer **30** corresponding to the opening **14***a* (the opening **13***a*) is exactly the potential difference between the lower conductive layer **12** and the counter electrode **22,** and the voltage drop (capacitance division) due to the dielectric layer **13** does not occur. In other words, all of the seven equipotential lines EQ drawn in **FIG. 34B** between the upper conductive layer **14** and the counter electrode **22** stay between the upper conductive layer **14** and the counter electrode **22** across the entire liquid crystal layer **30** (as opposed to **FIG. 1B** where one of the five equipotential lines EQ is drawn into the dielectric layer **13**), thereby applying a constant voltage across the entire picture element region.

[0304] Thus, by providing the opening **13***a* in the dielectric layer **13**, it is possible to apply the same voltage across the region of the liquid crystal layer **30** corresponding to the opening **13***a* as that applied across the other regions of the liquid crystal layer **30**. However, the thickness of the liquid crystal layer **30**, across which a voltage is applied, varies depending upon the location in each picture element region, whereby the change in retardation in the presence of an applied voltage also varies depending upon the location. If the degree of variation is significant, the display quality may deteriorate.

[0305] In the structure illustrated in **FIG. 34A** to **FIG. 34**C, the thickness d**1** of the liquid crystal layer **30** on the upper conductive layer **14** (excluding the opening **14***a*) and the thickness d**2** of the liquid crystal layer **30** on the lower conductive layer **12** exposed through the opening **14***a* (and the opening **13***a*) differ from each other by the thickness of the dielectric layer **13**. When the portion of the liquid crystal layer **30** having the thickness d**1** and the other portion of the liquid crystal layer **30** having the thickness d**2** are driven with the same voltage range, the amount of retardation change caused by the orientation change in the liquid crystal layer **30** varies therebetween by the influence of the difference in thickness between the respective portions of the liquid crystal layer **30**. When the relationship between the applied voltage and the amount of retardation of the liquid crystal layer **30** considerably varies depending upon the location, the following problem arises. That is, in a design where the display quality is given a higher priority, the transmittance is sacrificed, and when the transmittance is given a higher priority, the color temperature of the white display shifts, thereby sacrificing the display quality. Therefore, when the liquid crystal display device **500** is used as a transmission type liquid crystal display device, the thickness of the dielectric layer **13** is preferably small.

[0306] Next, a liquid crystal display device **600** in which the dielectric layer of the picture element electrode includes a depressed portion will be described with reference to **FIG. 35**, which shows a cross-sectional view illustrating the structure of one picture element region of the liquid crystal display device **600**.

[0307] The dielectric layer **13** of the picture element electrode **15** of the liquid crystal display device **600** includes a depressed portion **13***b* corresponding to the opening **14***a* of the upper conductive layer **14**. Other than this, the structure of the liquid crystal display device **600** is substantially the same as that of the liquid crystal display device **500** illustrated in **FIG. 34A** to **FIG. 34C**.

[0308] In the liquid crystal display device **600**, a portion of the dielectric layer **13** located in the opening **14***a* of the upper conductive layer **14** of the picture element electrode **15** is not completely removed, whereby the thickness d**3** of a portion of the liquid crystal layer **30** located in the opening **14***a* is smaller than the thickness d**2** of the corresponding portion of the liquid crystal layer **30** located in the opening **14***a* of the liquid crystal display device **500** by the thickness of the dielectric layer **13** in the depressed portion **13***b*. Moreover, the voltage applied across the region of the liquid crystal layer **30** in the opening **14***a* is subject to the voltage drop (capacitance division) due to the dielectric layer **13** in the depressed portion **13***b*, and thus is lower than the voltage applied across the region of the liquid crystal layer **30** on the upper conductive layer (the region thereof excluding the opening **14***a*). Therefore, by adjusting the thickness of the dielectric layer **13** in the depressed portion **13***b*, it is possible to control the relationship between the variations in retardation amount due to the difference in thickness of the liquid crystal layer **30** and the variations in the applied voltage across the liquid crystal layer **30** depending upon the location (the amount of decrease in the voltage applied across the liquid crystal layer in the opening **14***a*), so as to ensure that the relationship between the applied voltage and the retardation does not depend upon the location in the picture element region. More strictly, the relationship between the applied voltage and the retardation can be controlled to be uniform across the picture element region, thereby realizing a high-quality display, by adjusting the birefringence of the liquid crystal layer, thickness of the liquid crystal layer, the dielectric constant and the thickness of the dielectric layer, and the thickness (or depth) of the depressed portion of the dielectric layer. Particularly, as compared to a transmission type liquid crystal display device having a flat-surface dielectric layer, there is an advantage that the decrease in transmittance due to a decrease in the voltage applied across the region of the liquid crystal layer **30** corresponding to the opening **14***a* of the upper conductive layer **14** (the decrease in the light efficiency) is suppressed.

[0309] In the above description, the same voltage is applied to the upper conductive layer **14** and the lower conductive layer **12** of the picture element electrode **15**. When different voltages are applied to the lower conductive layer **12** and the upper conductive layer **14**, it is possible to increase the variety of structures of liquid crystal display devices capable of displaying an image without display non-uniformity. For example, in the structure where the dielectric layer **13** is provided in the opening **13***a* of the upper conductive layer **14**, a voltage lower than the voltage applied to the upper conductive layer **14** by the voltage drop due to the dielectric layer **13** is applied to the lower conductive layer **12**, whereby it is possible to prevent the voltage applied across the liquid crystal layer **30** from varying depending upon the location in the picture element region.

[0310] In the liquid crystal display device **500** and the liquid crystal display device **600** of Embodiment 4, as in the liquid crystal display device **100** of Embodiment 1, the liquid crystal molecules **30***a* incline, starting from those at the edge portion of the opening **14***a*, by the function of the inclined electric field produced by the two-layer picture element electrode **15** including the upper conductive layer **14** having the opening **14***a*, whereby the liquid crystal layer **30** in each picture element region takes a radially-inclined orientation about the opening **14***a*. The formation of a radially-inclined orientation will not be further described below.

[0311] The structure of the picture element electrode of the liquid crystal display device of the present embodiment will be described in greater detail with reference to **FIG. 36**A and **FIG. 36B**. Each of **FIG. 36**A and **FIG. 36B** is an enlarged cross-sectional view schematically illustrating a structure around the picture element electrode. **FIG. 36A** illustrates the structure of a picture element electrode where the upper conductive layer **14** is not formed on the side wall of the opening **13***a* of the dielectric layer **13**, and **FIG. 36B** illustrates the structure of another picture element electrode where the upper conductive layer **14** is formed on the side wall of the opening **13***a* of the dielectric layer **13**.

[0312] The liquid crystal display device **500** and the liquid crystal display device **600** respectively illustrated in **FIG. 34A** to **FIG. 34**C and **FIG. 35** both have the structure as illustrated in **FIG. 36A**. The picture element electrode structure illustrated in **FIG. 36A** is preferred over that illustrated in **FIG. 36B** for the following reason. In the picture element electrode structure illustrated in **FIG. 36**A, the inclined electric field produced at the edge portion of the opening **14***a* of the upper conductive layer **14** is more inclined (with a larger inclination angle), whereby the liquid crystal molecules **30***a* in the vicinity of the edge portion can be more stably inclined (in a uniquely defined direction). As can be seen from the equipotential lines EQ shown in **FIG. 36**A, since a portion of the equipotential lines EQ in the opening **14***a* is drawn into the side wall of the opening **13***a* of the dielectric layer **13**, the degree of inclination of the equipotential lines EQ at the edge portion of the opening **14***a* is greater than the inclination of the side wall. Thus, the liquid crystal molecules **30***a* whose orientation is regulated vertical to the surface of the side wall of the opening **13***a* (on the vertical alignment film (not shown) formed on the side surface) can be inclined in a uniquely defined direction (the counterclockwise direction in the illustrated example). Moreover, as can be seen from **FIG. 36**A, it is preferred that the inclination angle θ of the side wall is small so that the liquid crystal molecules **30***a* on the side wall of the opening **13***a* are inclined (rotated) in a uniquely defined direction by the inclined electric field.

[0313] In contrast, when the upper conductive layer **14** is formed on the side wall of the opening **13***a* of the dielectric layer **13**, the equipotential lines EQ are parallel to the surface of the upper conductive layer **14** on the side wall as shown in **FIG. 36**B, whereby the inclination of the equipotential lines EQ at the edge portion of the opening **14***a* is less steep than the inclination of the side wall. Therefore, the equipotential lines EQ are perpendicular to the liquid crystal molecules **30***a* whose orientation is regulated to be vertical to the surface of the side wall of the opening **13***a* of the dielectric layer **13** (the vertical alignment film (not shown) formed on the upper conductive layer), whereby the direction in which the liquid crystal molecules **30***a* incline may not be uniquely defined. A portion of the upper conductive layer **14** may overlap a portion of the lower conductive layer **12** so as to electrically connect the upper conductive layer **14** to the lower conductive layer **12**. In such a case, it is no longer necessary to separately provide contact holes for electrically connecting the upper conductive layer **14** to the lower conductive layer **12**. In this way, the aperture ratio can be improved particularly in a reflection type liquid crystal display device in which the upper conductive layer **14** formed on the flat surface (upper surface) of the dielectric layer **13** is used as a reflection electrode (reflection layer).

[0314] The above description of the structure where the dielectric layer **13** includes the opening **13***a* also applies to the structure where the dielectric layer **13** includes the depressed portion **13***b*.

[0315] A liquid crystal display device including a picture element electrode in which the upper conductive layer **14** includes one opening **14***a* for each picture element region has been described above as the liquid crystal display device of the present embodiment. However, the present embodiment is not limited to the above-described example, but may also be applied to a liquid crystal display device having a plurality of openings **14***a* for each picture element region. The above-described structure where the opening **13***a* or the depressed portion **13***b* is formed in the dielectric layer **13** corresponding to the opening **14***a* of the upper conductive layer **14** can be applied to any of the liquid crystal display devices described above in Embodiment 1.

EMBODIMENT 5

[0316] **FIG. 37**A and **FIG. 37B** schematically illustrate one picture element region of a liquid crystal display device **700** of Embodiment 5. **FIG. 37A** is across-sectional view of the liquid crystal display device **700**, and **FIG. 37B** is a plan view of the liquid crystal display device **700**. **FIG. 37A** is a cross-sectional view taken along line **37**A-**37**A' of **FIG. 37B**. The structure of the liquid crystal display device **700** is substantially the same as that of the liquid crystal display device **500** of Embodiment 4 except that the lower conductive layer **12** further includes an opening **12***a,* and thus the common elements will not be further described below.

[0317] The lower conductive layer of the picture element electrode **15** of the liquid crystal display device **700** includes the opening **12***a* in a region of the dielectric layer **13** which is exposed through the opening **13***a.* As illustrated in **FIG. 37**B, the circular opening **13***a* of the dielectric layer **13** is provided at the center of the picture element region, i.e., in a position corresponding to the circular opening **14***a* which is provided in the central portion of the upper conductive layer **14**. The opening **12***a* which is provided in the portion of the lower conductive layer **12** exposed through the opening **13***a* of the dielectric layer **13** is located at the center of the opening **14***a* and the opening **13***a.*

[0318] When a voltage is applied through the liquid crystal layer **30** of the liquid crystal display device **700**, an electric field represented by the equipotential lines EQ shown in **FIG. 37A** is produced. The equipotential lines EQ once drop at the edge portion EG of the opening **14***a* of the upper conductive layer **14** and further drop in the opening **12***a* of the lower conductive layer **12**.

[0319] Since an inclined electric field is also formed at the edge portion of the opening **12***a* of the lower conductive layer **12**, the orientation change of the liquid crystal molecules **30***a* in the liquid crystal layer **30** across which a voltage is applied occurs with the inclination of the liquid crystal molecules **30***a* at the edge portion of the opening **14***a* and at the edge portion of the opening **12***a* serving as a trigger, thereby forming a radially-inclined orientation about the liquid crystal molecules **30***a* which are vertically oriented at the center of the opening **12***a.* Thus, by providing the opening **12***a* at the center of the lower conductive layer **12** opposing the opening **14***a,* in addition to providing the opening **14***a* of the upper conductive layer **14**, the position of the radially-inclined orientation of the liquid crystal molecules **30***a* in the opening **14***a* can be accurately and stably controlled, whereby it is possible to further stabilize the radially-inclined orientation and improve the response speed.

[**0320**] Since no voltage is applied across the region of the liquid crystal layer **30** corresponding to the opening **12***a,* it is preferred that the opening **12***a* is not large. Typically, the diameter of the opening **12***a* is preferably about 8 μm or less. Since the opening **12***a* is only required to be provided at the center of the radially-inclined orientation, only one opening **12***a* at the center of each opening **14***a* is sufficient. As described above with respect to the opening **14***a,* the shape of the opening **12***a* is not limited to a circle and may alternatively be an ellipse or a polygon.

[**0321**] The function of the opening **12***a* has been described above with respect to the structure where the opening **13***a* is provided in the dielectric layer **13**. The opening **12***a* may alternatively be used with the structure where the depressed portion **13***b* is provided in the dielectric layer **13 (FIG. 35)** or the structure where the flat dielectric layer **13** is used (e.g., **FIG. 1A** to **FIG. 1C**). Thus, the structure where the lower conductive layer **12** of the picture element electrode **15** includes the opening **12***a* in a region opposing the opening **14***a* of the upper conductive layer **14**, which has been described above with respect to the liquid crystal display device **700**, can be suitably used in combination with any of the above-described liquid crystal display devices of Embodiments 1 and 2. However, since the opening **12***a* is small (typically, with a diameter of 8 μm or less), a sufficient effect may not be obtained when the dielectric layer **13** above the opening **12***a* is thick.

APPLICATION TO TRANSMISSION-REFLECTION TYPE LIQUID CRYSTAL DISPLAY DEVICE

[**0322**] A transmission-reflection type liquid crystal display device (hereinafter, referred to simply as a "two-way liquid crystal display device") refers to a liquid crystal display device which includes, in each picture element region, a transmission region displaying an image in a transmission mode and a reflection region displaying an image in a reflection mode. Typically, the transmission region and the reflection region are defined respectively by a transparent electrode and a reflection electrode. The reflection region can be defined by a structure using a combination of a reflection layer and a transparent electrode instead of the reflection electrode.

[**0323**] In the two-way liquid crystal display device, an image can be displayed in either the reflection mode or the transmission mode which can be switched from one to another, or an image can be displayed in both display modes at the same time. Therefore, for example, the reflection mode display can be used under an environment with bright ambient light, and the transmission mode display can be used under a dark environment. When both of these display modes are used at the same time, it is possible to suppress the decrease in the contrast ratio which is observed when a transmission mode liquid crystal display device is used under an environment with a bright ambient light (a state where light from a fluorescent lamp or sun light is directly incident upon the display plane at a certain angle). Thus, the two-way liquid crystal display device can compensate for the drawback of a transmission type liquid crystal display device. The ratio between the area of the transmission region and that of the reflection region can be suitably determined according to the application of the liquid crystal display device. For a liquid crystal display device which is used exclusively as a transmission type display device, the area ratio of the reflection region can be reduced to such a degree that an image cannot be displayed in a reflection mode, and it is still possible to compensate for the drawback of a transmission type liquid crystal display device described above.

[**0324**] The structure and operation of a two-way liquid crystal display device will now be described with reference to **FIG. 38**A, **FIG. 38**B and **FIG. 38C**. Two-way liquid crystal display devices **150**, **550** and **650**, respectively illustrated in **FIG. 38**A, **FIG. 38**B and **FIG. 38**C, have structures which are basically the same as those of the liquid crystal display device **100** of Embodiment 1, the liquid crystal display device **500** of Embodiment 4, and the liquid crystal display device **600** of Embodiment 4, respectively. The two-way liquid crystal display device is not limited to these illustrated examples. An alternative two-way liquid crystal display device can be obtained by employing any other liquid crystal display device described above in Embodiment 1, 2 and 3, while providing one of the upper electrode layer and the lower electrode layer as a transparent conductive layer and the other as a reflection conductive layer.

[**0325**] In the two-way liquid crystal display device **150** illustrated in **FIG. 38**A, an upper conductive layer **14**T of the picture element electrode **15** is made of a transparent: conductive layer, and a lower conductive layer **12**R is made of a conductive layer having a light-reflecting property (typically, a metal layer). Each picture element region defined by the picture element electrode **15** includes a reflection region R defined by the reflective lower conductive layer **12**R and a transmission region T defined by the transparent upper conductive layer **14**T. In view of the overlap between the transparent upper conductive layer **14**T and the reflective lower conductive layer **12**R and the contribution to the display of light which is incident upon the device in an inclined direction with respect to the substrate normal (the direction normal to the display plane), the reflection region R and the transmission region T overlap each other in the vicinity of the boundary therebetween. However, for the sake of simplicity, these regions are shown to be separate from each other, assuming a display mode such that light is incident in the substrate normal.

[**0326**] The basic structure of the two-way liquid crystal display device **150** is the same as that of the liquid crystal display device **100**, and therefore the liquid crystal layer thereof is driven substantially in the same manner as that of the liquid crystal display device **100**. Specifically, the liquid crystal layer **30** takes a stable radially-inclined orientation in the presence of an applied voltage by the function of the two-layer picture element electrode **15**, thereby realizing a liquid crystal display device having a desirable viewing angle characteristic.

[**0327**] The display operation of the two-way liquid crystal display device **150** will now be described.

[**0328**] When the two-way liquid crystal display device **150** is in a white display, light which is incident upon the transmission region T from a backlight (not shown) provided on the outer side (the lower side of the figure) of the TFT substrate **100**a passes successively through the substrate **11**, the dielectric layer **13**, and the transparent upper conductive layer **14**T and is emitted to the counter substrate **100**b side via the liquid crystal layer **30**. The light coming from the counter substrate **100**b side (typically, the ambient light) successively passes through the substrate **21**, the counter electrode **22**, the liquid crystal layer **30** and the dielectric layer **13**, and is incident upon the reflective lower conductive layer **12**R, by which it is reflected. The reflected light passes along the same path in the opposite direction and is emitted to the counter substrate **100**b side.

[**0329**] Thus, light contributing to the display in a transmission mode passes through the liquid crystal layer **30** only once, whereas light contributing to the display in a reflection mode passes therethrough twice. Therefore, when the same voltage is applied across the liquid crystal layer **30** which has a uniform thickness (d**5**) across the entire picture element region (the transmission region T and the reflection region R), the amount of change in the retardation due to the liquid crystal layer **30** which is experienced by the transmitted light and that experienced by the reflected light do not coincide with each other. As a result, in the presence of an applied voltage across the liquid crystal layer **30**, the same gray level cannot be produced at the same time by the transmitted light and the reflected light, thereby deteriorating the display quality.

[**0330**] However, the above-described problem can be avoided with the two-way liquid crystal display device **150** of the present invention, as will be described below.

[**0331**] Since the two-way liquid crystal display device **150** includes the two-layer picture element electrode **15**, the voltage applied across the reflection region R of the liquid crystal layer **30** (the voltage between the reflective lower conductive layer **12**R and the counter electrode **22**) is lower than the voltage applied across the transmission region T of the liquid crystal layer **30** (the voltage between the transparent upper conductive layer **14**T and the counter electrode **22**) by the influence of the voltage drop due to the dielectric layer **13** as described above with respect to the liquid crystal display device of Embodiment 1. As a result, the amount of change in the retardation due to the liquid crystal layer **30** in the reflection region R is less than the amount of change in the retardation due to the liquid crystal layer **30** in the transmission region T. Therefore, the amount of change in the retardation due to the liquid crystal layer **30** in the transmission region T and the amount of change in the retardation due to the liquid crystal layer **30** in the reflection region R can be brought closer to each other by adjusting the birefringence and thickness of the liquid crystal layer **30** and the dielectric constant and thickness of the dielectric layer **13**. In other words, the influence of the optical path length on the retardation of the reflected light can be compensated for by adjusting the applied voltage.

[**0332**] As described above, when the two-way liquid crystal display device **150** of the present invention is used, the voltage-transmittance characteristics in the transmission mode and the voltage-reflectance characteristics in the reflection mode can be brought closer to each other. Thus, it is possible to obtain a transmission-reflection type liquid crystal display device having a desirable viewing angle characteristic in all azimuthal angles and a high visibility in any environment.

[**0333**] Next, the structure and operation of the two-way liquid crystal display device **550** will be described with reference to **FIG. 38B**. The picture element electrode **15** of the two-way liquid crystal display device **550** includes an upper conductive layer **14**R which is made of a conductive layer having a light-reflecting property and a lower conductive layer **12**T which is made of a transparent conductive layer. Each picture element region defined by the picture element electrode **15** includes a reflection region R defined by the reflective upper conductive layer **14**R and a transmission region T defined by the transparent lower conductive layer **12**T. Other than this, the basic structure of the two-way liquid crystal display device **550** is as that of the liquid crystal display device **500** illustrated in **FIG. 34A** to **FIG. 34**C, and thus will not be further described below.

[**0334**] The thickness of the liquid crystal layer **30** in the region other than the opening **14**a of the reflective upper conductive layer **14**R of the two-way liquid crystal display device **550** (i.e., in the reflection region R) will be denoted as d**1**, and the thickness of the liquid crystal layer **30** in the opening **14**a of the reflective upper conductive layer **14**R and the opening **13**a of the dielectric layer **13** (i.e., in the transmission region T) will be denoted as d**2**. Light which contributes to the reflection mode display (the reflected light) passes twice through the liquid crystal layer **30** in the reflection region R having the thickness d**1**. Light which contributes to the transmission mode display (the transmitted light) passes once through the liquid crystal layer **30** in the transmission region T having the thickness d**2**. Therefore, when the dielectric layer **13** is designed so as to have a thickness equal to d**1**, then, d**1**=d**2**/2. Thus, the total distance which the reflected light travels through the liquid crystal layer **30** can be matched with the distance the transmitted light travels through the liquid crystal layer **30**. Since the picture element electrode **15** of the two-way liquid crystal display device **550** has a structure where the transparent lower conductive layer **12**T is exposed in the opening **13**a of the dielectric layer **13** (a structure where no dielectric layer **13** exists on the transparent lower conductive layer **12**T), the voltage applied across the liquid crystal layer **30** in the transmission region T is equal to the voltage applied across the liquid crystal layer **30** in the reflection region R.

[**0335**] Therefore, when the thickness d**1** of the liquid crystal layer **30** in the reflection region R and the thickness d**2** of the liquid crystal layer **30** in the transmission region T satisfy the relationship of 2·d**1**=d**2**, the amount of change in the retardation due to the liquid crystal layer **30** which is experienced by the transmitted light and that experienced by the reflected light do coincide with each other in the presence of the same applied voltage across the reflective lower conductive layer **12**R and the transparent upper conductive layer **14**T. However, when the thickness of the liquid crystal layer **30** in the reflection region R is different from that in the transmission region T, the strength of the electric field produced may differ between these regions for the same applied voltage. Therefore, it is more preferred that the relationship between d**1** and d**2** is shifted from 2·d**1**=d**2** in view of the difference in electric field strength.

[**0336**] As described above, when the two-way liquid crystal display device **550** of the present invention is used, the voltage-transmittance characteristics in the transmission mode and the voltage-reflectance characteristics in the reflection mode can be brought closer to each other. Thus, it is possible to obtain a transmission-reflection type liquid crystal display device having a desirable viewing angle characteristic in all azimuthal angles and a high visibility in any environment.

[**0337**] Next, the structure and operation of the two-way liquid crystal display device **650** will be described with reference to **FIG. 38C**. The picture element electrode **15** of the two-way liquid crystal display device **650** includes the upper conductive layer **14**R which is made of a conductive layer having a light-reflecting property and the lower conductive layer **12**T which is made of a transparent conductive layer. Each picture element region defined by the picture element electrode **15** includes a reflection region R defined by the reflective upper conductive layer **14**R and a transmission region T defined by the transparent lower conductive layer **12**T. Other than this, the basic structure of the two-way liquid crystal display device **650** is as that of the liquid crystal display device **600** illustrated in **FIG. 35**, and thus will not be further described below.

[**0338**] The thickness of the liquid crystal layer **30** in the region other than the opening **14***a* of the reflective upper conductive layer **14**R of the two-way liquid crystal display device **650** (i.e., in the reflection region R) will be denoted as d**1**, and the thickness of the liquid crystal layer **30** in the opening **14***a* of the reflective upper conductive layer **14**R and the depressed portion **13***b* of the dielectric layer **13** (i.e., in the transmission region T) will be denoted as d**3**. The thickness d**3** of the liquid crystal layer **30** in the transmission region T is greater than the thickness d**1** of the liquid crystal layer **30** in the reflection region R by the depth of the depressed portion **13***b* of the dielectric layer **13**. Light which contributes to the reflection mode display (the reflected light) passes twice through the liquid crystal layer **30** in the reflection region R having the thickness d**1**. Light which contributes to the transmission mode display (the transmitted light) passes once through the liquid crystal layer **30** in the transmission region T having the thickness d**3**. Thus, the distance the transmitted light travels through the liquid crystal layer **30** is d**3**, and the distance the reflected light travels through the liquid crystal layer **30** is 2·d**1**.

[**0339**] The voltage applied across the liquid crystal layer **30** in the transmission region T is subject to a voltage drop (capacitance division) due to the dielectric layer **13** in the depressed portion **13***b*, and thus is lower than the voltage applied across the liquid crystal layer **30** in the reflection region R. Therefore, by adjusting the thickness of the dielectric layer **13** in the depressed portion **13***b*, it is possible to control the relationship between the variations in retardation amount due to the difference in the distance light travels through the liquid crystal layer **30** and the variations in the applied voltage across the liquid crystal layer **30** depending upon the location (the amount of decrease in the voltage applied across the liquid crystal layer **30** in the transmission region T), so that the relationship between the applied voltage and the retardation in the transmission region T is matched with that in the reflection region R. More strictly, the relationship between the applied voltage and the retardation can be controlled to be uniform across the transmission region and the reflection region, by adjusting the birefringence of the liquid crystal layer, thickness of the liquid crystal layer, the dielectric constant and the thickness of the dielectric layer, and the thickness (or depth) of the depressed portion of the dielectric layer.

[**0340**] As described above, when the two-way liquid crystal display device **650** of the present invention is used, the voltage-transmittance characteristics in the transmission mode and the voltage-reflectance characteristics in the reflection mode can be brought closer to each other. Thus, it is possible to obtain a transmission-reflection type liquid crystal display device having a desirable viewing angle characteristic in all azimuthal angles and a high visibility in any environment.

[**0341**] In **FIG. 38**A, **FIG. 38**B and **FIG. 38C** illustrating the two-way liquid crystal display devices **150, 550** and **650**, respectively, the surface of the reflective conductive layer (upper or lower conductive layer) is shown to be flat. Alternatively, the surface of the reflective conductive layer may be processed into a configuration with concave/convex portions, thereby providing a function of diffuse-reflecting (or scattering) light. By providing the reflective conductive layer with the light-diffusing function, it is possible to realize a reflection mode display with no parallax and with a high display quality.

[**0342**] A method for providing the surface of the reflective conductive layer with concave/convex portions may be, for example, the method disclosed in Japanese Laid-Open Patent Publication No. 6-75238.

[**0343**] For example, the dielectric layer **13** is formed by using a photoresist (of either a negative or positive type), and the surface of the resist layer is processed into a configuration with concave/convex portions through a photolithography process using a photomask having a predetermined pattern of light-transmitting portions (or light-blocking portions). As necessary, the resist layer having the concave/convex portions formed thereon may be heated so as to smoothen the concave/convex portions (into a continuous wavy configuration) through a phenomenon of the surface of the resist layer being deformed by heat (thermal deformation). By forming a reflective upper conductive layer on the surface of the dielectric layer **13** having the concave/convex portions formed thereon, it is possible to form concave/convex portions on the surface of the reflective upper conductive layer.

[**0344**] However, when using the reflective upper conductive layer **14**R as in the two-way liquid crystal display devices **550** and **650** illustrated in **FIG. 38**B and **FIG. 38**C, it is preferred that the height of the dielectric layer **13** at the edge portion of the opening **14***a* is uniform as illustrated in **FIG. 40**A and **FIG. 40B**.

[**0345**] In the liquid crystal display device of the present invention, the liquid crystal molecules are oriented in a radially-inclined orientation by utilizing an inclined electric field which is produced at the edge portion of the opening **14***a* by the two-layer picture element electrode **15** including the reflective upper conductive layer **14**R having the opening **14***a*.

[**0346**] However, if the concave/convex portions formed on the surface of the dielectric layer **13** (in the figure, each circle schematically illustrates a concave portion or a convex portion) are arranged to overlap the opening **13***a* or the depressed portion **13***b* of the dielectric layer **13**, as illustrated in **FIG. 39**A, the thickness of the dielectric layer **13** at the edge portion of the opening **14***a* varies depending upon the location as illustrated in **FIG. 39B**. If the concave/convex portions exist on the surface of the dielectric layer **13** at the edge portion, the direction of the inclined electric field produced at the edge portion (the inclination direction of the equipotential line) varies depending upon the location, whereby the stability of the radially-inclined orientation about the opening **14***a* may decrease, or the state of the radially-inclined orientation may vary depending upon the location of the opening **14***a*.

[**0347**] In view of this, the surface of the dielectric layer **13** around the opening **14***a* (the opening **13***a* or the depressed portion **13***b* of the dielectric layer **13**) may be made flat without providing the concave/convex portions, as illustrated in **FIG. 40**A, it is possible to obtain a structure where the dielectric layer **13** in the vicinity of the edge portion has a uniform thickness along the entire periphery of the opening **14***a,* as illustrated in **FIG. 40B**.

[**0348**] Instead of providing the reflective conductive layer with a light-diffusing function by processing the surface of the reflective conductive layer into a configuration with concave/convex portions, a diffusion layer having a light-diffusing function may be provided on the light-receiving side of the reflective conductive layer. The diffusion layer may be provided either on the inner side of the liquid crystal panel (one side of the substrate which is closer to the liquid crystal layer) or on the outer side (the viewer side). It is preferred that the diffusion layer is provided selectively in the reflection region of the liquid crystal display device.

ARRANGEMENT OF POLARIZING PLATE AND PHASE PLATE

[**0349**] A so-called "vertical alignment type liquid crystal display device", including a liquid crystal layer in which liquid crystal molecules having a negative dielectric anisotropy are vertically aligned in the absence of an applied voltage, is capable of displaying an image in various display modes. Among others, the birefringence mode, in which an image is displayed by controlling the birefringence of the liquid crystal layer with an electric field, is preferred in terms of the display quality. The arrangement of polarizing plates and phase plates (wave plates) for improving the display quality of a birefringence-mode vertical alignment type liquid crystal display device will now be described. It is possible to obtain a birefringence-mode liquid crystal display device by providing a pair of polarizing plates on the outer side (the side away from the liquid crystal layer **30**) of the pair of substrates (e.g., the TFT substrate and the counter substrate) of any of the liquid crystal display devices described above in Embodiments 1 to 5.

[**0350**] First, the arrangement of polarizing plates will be described with reference to **FIG. 41**A, **FIG. 41**B, **FIG. 42**A and **FIG. 42B**. **FIG. 41**A and **FIG. 41B** illustrate a state in the absence of an applied voltage (OFF state), and **FIG. 42**A and **FIG. 42B** illustrate a state in the presence of an applied voltage (ON state).

[**0351**] **FIG. 41A** is a cross-sectional view schematically illustrating a liquid crystal display device **100A** including polarizing plates **50***a* and **50***b* on the outer side of the TFT substrate **100***a* and counter substrate **100***b,* respectively. The liquid crystal display device **100A** may be any of the liquid crystal display devices of Embodiments 1 to 5. The liquid crystal molecules **30***a* in the liquid crystal layer **30** are in a vertical alignment in the absence of an applied voltage, as illustrated in **FIG. 41A**.

[**0352**] **FIG. 41B** schematically illustrates the arrangement of the respective transmission axes (polarization axes) PA of the polarizing plates **50***a* and **50***b* as the liquid crystal display device **100**A is viewed in the direction normal to the display plane (substrate normal) from the counter substrate **100***b* side (the viewer side). The solid line arrow in the figure denotes the transmission axis PA1 of the (upper) polarizing plate **50***b,* and the broken line arrow denotes the transmission axis PA2 of the (lower)polarizing plate **50***a*. As illustrated in **FIG. 41**B, the transmission axes PA2 and PA1 of the polarizing plates **50***a* and **50***b* are arranged so as to be perpendicular to each other. In other words, the polarizing plates **50***a* and **50***b* are arranged in a crossed-Nicols state.

[**0353**] Since the axial orientation of the liquid crystal molecules **30***a* of the liquid crystal layer **30** in the absence of an applied voltage is vertical to the display plane, the liquid crystal molecules **30***a* do not give a phase difference to polarized light which is vertically incident upon the liquid crystal layer **30**. The phrase "vertical to the liquid crystal layer **30**" as used herein refers to being vertical to the plane of the liquid crystal layer **30** which is parallel to the substrates **100***a* and **100***b*.

[**0354**] The liquid crystal layer **30** in a vertical alignment does not give a phase difference to the polarized light which is vertically incident upon the liquid crystal layer **30**. Therefore, for example, the light which is vertically incident upon the liquid crystal layer **30** from the TFT substrate **100***a* side becomes linearly-polarized light having a polarization direction along the transmission axis PA2 as it passes through the polarizing plate **50***a,* and is vertically incident upon the liquid crystal layer **30**. Thus, the light passes through the liquid crystal layer **30** while maintaining its polarization direction and is incident upon the polarizing plate **50***b*. Since the transmission axes PA2 and PA1 of the polarizing plate **50***a* and the polarizing plate **50***b* are perpendicular to each other, the linearly-polarized light having passed through the counter substrate **100***b* is absorbed by the polarizing plate **50***b*. As a result, the liquid crystal display device **100**A produces a black display in the absence of an applied voltage.

[**0355**] In the presence of an applied voltage, the liquid crystal molecules **30***a* are in a radially-inclined orientation as illustrated in **FIG. 42**A and **FIG. 42B**. While only one radially-inclined orientation region is shown in **FIG. 42**A and **FIG. 42B** for the sake of simplicity, a plurality of radially-inclined orientation regions may be formed in each picture element region as described above in Embodiments 1 to 5. This also applies to other subsequent figures.

[**0356**] The liquid crystal layer **30** including the liquid crystal molecules **30***a* in a radially-inclined orientation produces a display as follows. For example, light which is vertically incident upon the liquid crystal layer **30** from the TFT substrate **100***a* side becomes linearly-polarized light having a polarization direction along the transmission axis PA2 as it passes through the polarizing plate **50***a,* and is vertically incident upon the liquid crystal layer **30**. The liquid crystal molecules **30***a* which are oriented so that the axial orientation thereof as viewed in the substrate normal direction is parallel or perpendicular to the polarization direction of the linearly-polarized light and the liquid crystal molecules **30***a* which are in a vertical alignment (the liquid crystal molecules which are located at the center of the radially-inclined orientation) do not give a phase difference to the linearly-polarized light which is vertically incident upon the liquid crystal layer **30**. Therefore, linearly-polarized light incident upon a region where the liquid crystal molecules **30***a* have such an orientation direction passes through the liquid crystal layer **30** while maintaining its polarization direction, and is incident upon the polarizing plate **50***b* through the counter substrate **100***b*. Since the transmission axes PA2 and PA1 of the polarizing plate **50***a* and the polarizing plate **50***b* are perpendicular to each other, the linearly-polarized light is absorbed by the polarizing plate **50***b*. As a result, a portion of the radially-inclined orientation region of the liquid crystal layer **30** produces a black display even in the presence of an applied voltage.

[**0357**] On the other hand, another portion of the linearly-polarized light (having a polarization direction parallel to the transmission axis PA2 of the polarizing plate **50***a*) which is incident upon a region including other liquid crystal molecules **30***a* (the liquid crystal molecules other than those whose axial orientation as viewed in the substrate normal direction is parallel or perpendicular to the polarization direction of the linearly-polarized light and those which are in a vertical alignment) is given a phase difference by the liquid crystal layer **30**. Thus, the linear polarization collapses and the linearly-polarized light becomes elliptically-polarized light. The phase difference is maximum in a region where the polarization direction of the incident linearly-polarized light and the axial orientation of the liquid crystal molecules **30***a* as viewed in the substrate normal direction make an angle of 45°, and gradually decreases as the axial orientation of the liquid crystal molecules **30***a* as viewed in the substrate normal direction becomes more parallel or perpendicular to the polarization direction of the incident linearly-polarized light. Therefore, in a region where the molecular axis of the liquid crystal molecules **30***a* is not parallel to the substrate normal direction and where the axial orientation of the liquid crystal molecules **30***a* as viewed in the substrate normal direction is not parallel or perpendicular to the polarization direction of the incident linearly-polarized light, the linearly-polarized light incident upon the liquid crystal layer **30** is given a phase difference, whereby the linear polarization thereof collapses (typically, such light becomes elliptically-polarized light). Therefore, when polarized light whose polarization has been converted to another through the liquid crystal layer **30** is incident upon the polarizing plate **50***b,* a portion of such light is transmitted through the polarizing plate **50***b*. The amount of the polarized light to be transmitted depends upon the magnitude of the phase difference given by the liquid crystal layer **30**, and thus can be adjusted by controlling the voltage to be applied across the liquid crystal layer **30**. Thus, a gray-scale display can be produced by controlling the voltage to be applied across the liquid crystal layer **30**.

[**0358**] λ/4 PLATE

[**0359**] The display quality can be further improved by providing a quarter-wave plate (λ/4 Plate) between the liquid crystal layer and at least one of the pair of polarizing plates provided on opposing sides of the liquid crystal layer. Specifically, the light efficiency can be increased by an arrangement such that circularly-polarized light is incident upon the liquid crystal layer **30** exhibiting a radially-inclined orientation. For example, in the liquid crystal display device disclosed in Japanese Laid-Open Patent Publication No. 10-301114, in which linearly-polarized light is incident upon the vertical alignment type liquid crystal layer of a 4-division multi-domain orientation, the boundary region between adjacent domains of the multi-domain orientation cannot contribute to the display. In contrast, with a structure where circularly-polarized light is incident upon a liquid crystal layer exhibiting a radially-inclined orientation through which the orientation direction changes continuously, it is possible to realize a liquid crystal display device having a higher brightness (higher light efficiency).

[**0360**] The function of a λ/4 plate will be described with reference to **FIG. 43**A, **FIG. 43**B, **FIG. 44**A and **FIG. 44B**. **FIG. 43**A and **FIG. 43B** schematically illustrate a state in the absence of an applied voltage, and **FIG. 44**A and **FIG. 44B** schematically illustrate a state in the presence of an applied voltage. In this specification, unless otherwise noted, the term "λ/4 plate" refers to a single layer λ/4 plate, and a phase plate which is made of a plurality of phase plates laminated together and which as a whole satisfies the λ/4 conditions will be referred to particularly as a "broadband λ/4 plate". In the following description, a structure using a single-layer λ/4 plate will be described.

[**0361**] A liquid crystal display device **100**B illustrated in **FIG. 43**A, **FIG. 43**B, **FIG. 44**A and **FIG. 44B** uses the liquid crystal display device **100**, and further includes the polarizing plates **50***a* and **50***b* and λ/4 plates **60***a* and **60***b* provided on the opposing sides thereof. Each of the λ/4 plates **60***a* and **60***b* is a phase plate which converts linearly-polarized light whose polarization direction is 45° with respect to the slow axis thereof into circularly-polarized light, or vice versa. Any of the liquid crystal display devices described above in Embodiments 1 to 5 may be used instead of the liquid crystal display device **100**.

[**0362**] The liquid crystal display device **100**B includes the λ/4 plate **60***a* between the TFT substrate **100***a* and the polarizing plate **50***a* which is provided on the outer side (the side away from the liquid crystal layer **30**) of the TFT substrate **100***a,* and the λ/4 plate **60***b* between the counter substrate **100***b* and the polarizing plate **50***b* which is provided on the outer side of the counter substrate **100***b*. The respective transmission axes PA2 and PA1 of the polarizing plates **50***a* and **50***b* and respective slow axes SL2 and SL1 of the λ/4 plates **60***a* and **60***b* are arranged as illustrated in **FIG. 43B**.

[**0363**] The slow axis SL2 of the λ/4 plate **60***a* is at an angle of 45° with respect to the transmission axis PA2 of the polarizing plate **50***a,* and the slow axis SL1 of the λ/4 plate **60***b* is at an angle of 45° with respect to the transmission axis PA1 of the polarizing plate **50***b*. The respective transmission axes PA1 and PA2 and the slow axes SL1 and SL2 are arranged so that each pair of axes form an angle of 45° in the same direction (for example, as viewed in the substrate normal direction from the counter substrate **100***b* side, the slow axes SL1 and SL2 are 45° away from the respective transmission axes PA1 and PA2 both in the clockwise direction, as illustrated in the figure, or both in the counter-clockwise direction).

[**0364**] The liquid crystal layer **30** is in a vertical alignment in the absence of an applied voltage, as illustrated in **FIG.**

43A, and thus does not give a phase difference to light which is vertically incident upon the liquid crystal layer **30**. Therefore, for example, light which is vertically incident upon the liquid crystal layer **30** from the TFT substrate **10***a* side passes through the polarizing plate **50***a,* becomes linearly-polarized light whose polarization direction is 45° with respect to the slow axis SL**2** of the λ/4 plate **60***a,* and is incident upon the λ/4 plate **60***a*. The linearly-polarized light is converted into circularly-polarized light as it passes through the λ/4 plate **60***a*. The circularly-polarized light passes through the liquid crystal layer **30** while maintaining its polarization, and is incident upon the λ/4 plate **60***b*. The circularly-polarized light becomes linearly-polarized light whose polarization direction is 45° with respect to the slow axis SL**1** as it passes through the λ/4 plate **60***b,* and is incident upon the polarizing plate **50***b*. The polarization direction of the linearly-polarized light having passed through the λ/4 plate **60***b* is perpendicular to the transmission axis PA**1** of the polarizing plate **50***b*. Therefore, the linearly-polarized light is absorbed by the polarizing plate **50***b*. Thus, the liquid crystal display device **100**B produces a black display in the absence of an applied voltage.

[**0365**] In the presence of an applied voltage, the liquid crystal molecules **30***a* are in a radially-inclined orientation as illustrated in **FIG. 44**A and **FIG. 44B**.

[**0366**] The liquid crystal layer **30** including the liquid crystal molecules **30***a* which are in a radially-inclined orientation gives light incident upon the liquid crystal layer **30** a phase difference according to the polarization direction thereof. For example, light which is vertically incident upon the liquid crystal layer **30** from the TFT substrate **100***a* side becomes linearly-polarized light whose polarization direction is 45° with respect to the slow axis SL**1** of the λ/4 plate **60***a* as it passes through the polarizing plate **50***a,* and is incident upon the λ/4 plate **60***a*. The linearly-polarized light is converted into circularly-polarized light as it passes through the λ/4 plate **60***a*. The liquid crystal molecules **30***a* in a vertical alignment (those liquid crystal molecules located at the center of a radially-inclined orientation) do not give a phase difference to the polarized light which is vertically incident upon the liquid crystal layer **30**. Therefore, the circularly-polarized light incident upon a region in which the liquid crystal molecules **30***a* are in a vertical alignment passes through the liquid crystal layer **30** while maintaining its polarization, and is incident upon the λ/4 plate **60***b*. The circularly-polarized light becomes linearly-polarized light whose polarization direction is 45° with respect to the slow axis SL**1** as it passes through the λ/4 plate **60***b,* and is incident upon the polarizing plate **50***b*. The polarization direction of the linearly-polarized light having passed through the λ/4 plate **60***b* is perpendicular to the transmission axis PA**1** of the polarizing plate **50***b*. Therefore, the linearly-polarized light is absorbed by the polarizing plate **50***b*. Thus, a portion of the radially-inclined orientation region of the liquid crystal layer **30** (only the vertical alignment region) produces a black display even in the presence of an applied voltage.

[**0367**] On the other hand, a portion of the circularly-polarized light (which has resulted through the conversion from linearly-polarized light by the λ/4 plate **60***b*) which is incident upon the region including the liquid crystal molecules **30***a* other than those in a vertical alignment is given a phase difference by the liquid crystal layer **30**. Thus, the polarization of the circularly-polarized light changes (typically, such light becomes elliptically-polarized light). Therefore, a portion of the polarized light having passed through the λ/4 plate **60***b* passes through the polarizing plate **50***b*. The amount of the polarized light to be transmitted depends upon the magnitude of the phase difference given by the liquid crystal layer **30**, and thus can be adjusted by controlling the voltage to be applied across the liquid crystal layer **30**. Thus, a gray-scale display can be produced by controlling the voltage to be applied across the liquid crystal layer **30**.

[**0368**] As described above, in the liquid crystal display device **100**B further including the λ/4 plates **60***a* and **60***b,* the only region which produces a black display in the presence of an applied voltage is the vertical alignment region (the center of the radially-inclined orientation), whereby there is less region which produces a black display in the presence of an applied voltage as compared to the liquid crystal display device **100**A in which the vertical alignment region and also the region where the liquid crystal molecules are oriented in a direction parallel or perpendicular to the transmission axis of a polarizing plate produce a black display in the presence of an applied voltage. Thus, the liquid crystal display device **100**B has a higher light efficiency (effective aperture ratio) than that of the liquid crystal display device **100**A, thereby realizing a display with a higher brightness.

[**0369**] Generally, it is not easy to completely eliminate the wavelength dispersion of the single-layer λ/4 plates **60***a* and **60***b*. For example, when a λ/4 plate which is designed so as to satisfy the λ/4 conditions for light having a wavelength of 550 nm (light of the highest visibility) is used for the λ/4 plates **60***a* and **60***b,* the λ/4 plate shifts away from the λ/4 conditions as the wavelength of light shifts away from 550 nm. As a result, when the liquid crystal display device **100**B is producing a black display, visible light whose wavelength is shifted from the 550 nm passes through the polarizing plate **50***b,* thereby causing the coloring phenomenon.

[**0370**] In order to suppress the coloring phenomenon in a black display, the transmission axes PA**2** and PA**1** of the polarizing plates **50***a* and **50***b* can be arranged perpendicular to each other with the slow axes SL**2** and SL**1** of the λ/4 plates **60***a* and **60***b* being also arranged perpendicular to each other, as in a liquid crystal display device **100**C illustrated in **FIG. 45**A and **FIG. 45B**. The transmission axis PA**2** of the polarizing plate **50***a* and the slow axis SL**2** of the λ/4 plate **60***a* form an angle of 45° and the transmission axis PA**1** of the polarizing plate **50***b* and the slow axis SL**1** of the λ/4 plate **60***b* also form an angle of 45° in the same direction, as in the liquid crystal display device **100**B. When the slow axis SL**2** of the λ/4 plate **60***a* and the slow axis SL**1** of the λ/4 plate **60***b* are arranged perpendicular to each other, as described above, the wavelength dispersion of refractive index anisotropy of the λ/4 plate **60***a* and that of the λ/4 plate **60***b* are canceled out by each other. As a result, visible light over a wide wavelength range is absorbed by the polarizing plate **50***b* in a black display, thereby realizing a desirable black display. Particularly, it is preferred to use the same λ/4 plate (or at least λ/4 plates made of the same material) as the λ/4 plate **60***a* and as the λ/4 plate **60***b*. With such a structure, it is possible to produce a liquid crystal display device at a lower cost as compared to the structure with a broadband λ/4 plate to be described below.

[0371] Another approach for suppressing the occurrence of the coloring phenomenon in a black display due to the wavelength dispersion of refractive index anisotropy of the single-layer λ/4 plates **60***a* and **60***b*, as described above, is to use a broadband λ/4 plate in place of a single λ/4 plate. A broadband λ/4 plate is made of a plurality of phase plates laminated together so as to cancel out the influence of the wavelength dispersion, thereby satisfying the λ/4 conditions across the entire visible range (400 nm to 800 nm). For example, a broadband λ/4 plate can be produced by laminating together a single-layer λ/4 plate and a single-layer half-wave plate (hereinafter, referred to as a "λ/2 plate").

[0372] A liquid crystal display device **100**D illustrated in **FIG. 46A** to **FIG. 46C** includes the polarizing plates **50***a* and **50***b*, the λ/4 plates **60***a* and **60***b*, and λ/2 plates **70***a* and **70***b* respectively on the opposing sides of the liquid crystal display device **100**. On the outer side (the side away from the liquid crystal layer **30**) of the TFT substrate **100***a*, the λ/4 plate **60***a*, the λ/2 plate **70***a* and the polarizing plate **50***a* are provided in this order from the liquid crystal layer **30** side. On the outer side of the counter substrate **100***b*, the λ/4 plate **60***b*, the λ/2 plate **70***b* and the polarizing plate **50***b* are provided in this order from the liquid crystal layer **30** side.

[0373] The λ/4 plate **60***b*, the λ/2 plate **70***b* and the polarizing plate **50***b* are provided on the counter substrate **100***b* so that the respective optical axes are arranged as illustrated in **FIG. 46B**. The arrangement is such that the angle between the transmission axis PA**1** of the polarizing plate **50***b* and the slow axis SL**1** of the λ/4 plate **60***b* is 2α±45°, wherein α(°) denotes the angle between the transmission axis PA**1** of the polarizing plate **50***b* and the slow axis SL**3** of the λ/2 plate **70***b*.

[0374] On the other hand, the λ/4 plate **60***a*, the λ/2 plate **70***a* and the polarizing plate **50***a* are provided on the TFT substrate **100***a* so that the respective optical axes are arranged as illustrated in **FIG. 46C**. The arrangement is such that the angle between the transmission axis PA**2** of the polarizing plate **50***a* and the slow axis SL**2** of the λ/4 plate **60***a* is 2β±45°, wherein β(°) denotes the angle between the transmission axis PA**2** of the polarizing plate **50***a* and the slow axis SL**4** of the λ/2 plate **70***a*. Moreover, the angle (2β±45°) between the transmission axis PA**2** of the polarizing plate **50***a* and the slow axis SL**2** of the λ/4 plate **60***a* is selected so as to have the same sign as that of the angle (2α±45°) between the transmission axis PA**1** of the polarizing plate **50***b* and the slow axis SL**1** of the λ/4 plate **60***b*. That is, the arrangement is such that the angle between the transmission axis PA**2** and the slow axis SL**2** is 2β+45° when the angle between the transmission axis PA**1** and the slow axis SL**1** is 2α+45 °.

[0375] Light vertically incident upon the liquid crystal layer **30** in a vertical alignment from the TFT substrate **100***a* side becomes linearly-polarized light as it passes through the polarizing plate **50***a*. Then, it passes through the λ/2 plate **70***a* and becomes linearly-polarized light having a polarization direction at an angle of 2β with respect to the transmission axis PA**2** of the polarizing plate **50***a*. The linearly-polarized light is incident upon the λ/4 plate **60***a* and is converted into circularly-polarized light. The circularly-polarized light passes through the liquid crystal layer **30** while maintaining its polarization, and is incident upon the λ/4 plate **60***b*. The light is converted by the λ/4 plate **60***b* into linearly-polarized light whose polarization direction is at an angle of 45° with respect to the slow axis SL**1** of the λ/4 plate **60***b*. The linearly-polarized light is incident upon the λ/2 plate **70***b*, becomes linearly-polarized light whose polarization direction is at an angle of 2β+45° with respect to the slow axis SL**1** of the λ/4 plate **60***b*, and is then incident upon the polarizing plate **50***b*. The polarization direction of the linearly-polarized light having passed through the λ/2 plate **70***b* is perpendicular to the transmission axis PA**1** of the polarizing plate **50***b*, and thus the linearly-polarized light is absorbed by the polarizing plate **50***b*. Thus, the liquid crystal display device **100D** produces a black display in the absence of an applied voltage.

[0376] In the liquid crystal display device **100**D, the λ/2 plate **70***a* and the λ/2 plate **70***b* are provided respectively between the λ/4 plate **60***a* and the polarizing plate **50***a* and between the λ/4 plate **60***b* and the polarizing plate **50***b*, and the λ/2 plate **70***a* and the λ/2 plate **70***b* reduce the wavelength dispersion of refractive index anisotropy of the λ/4 plates **60***a* and **60***b*, respectively, thereby realizing a desirable black display without coloring.

[0377] In order to further suppress the occurrence of the coloring phenomenon in a black display, it is possible to employ the structure of a liquid crystal display device **100E** as illustrated in **FIG. 47A** to **FIG. 47**C, in which the transmission axes PA**2** and PA**1** of the polarizing plates **50***a* and **50***b* are perpendicular to each other,

What is claimed is:

1. A liquid crystal display device, comprising:

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

a plurality of picture element regions each defined by a first electrode provided on one side of the first substrate which is closer to the liquid crystal layer and a second electrode provided on the second substrate so as to oppose the first electrode via the liquid crystal layer, wherein:

the liquid crystal layer in each of the plurality of picture element regions takes a vertical alignment in the absence of an applied voltage between the first electrode and the second electrode, and changes its orientation according to a voltage applied between the first electrode and the second electrode;

the first electrode includes a lower conductive layer, a dielectric layer covering at least a portion of the lower conductive layer, and an upper conductive layer provided on one side of the dielectric layer which is closer to the liquid crystal layer; and

the upper conductive layer includes at least one first opening, and the lower conductive layer is provided so as to oppose at least a portion of the at least one first opening via the dielectric layer.

2. The liquid crystal display device of claim 1, wherein the lower conductive layer is provided in a region including a region opposing the at least one first opening via the dielectric layer.

3. The liquid crystal display device of claim 1, wherein the at least one first opening has a square shape.

4. The liquid crystal display device of claim 1, wherein the at least one first opening has a circular shape.

5. The liquid crystal display device of claim 1, wherein the at least one first opening of the upper conductive layer includes a plurality of first openings.

6. The liquid crystal display device of claim 5, wherein the plurality of first openings of the upper conductive layer are regularly arranged.

7. The liquid crystal display device of claim 1, wherein the dielectric layer includes a depressed portion or an opening in the at least one first opening.

8. The liquid crystal display device of claim 1, wherein the lower conductive layer includes a second opening in a region opposing the first opening.

9. The liquid crystal display device of claim 1, wherein one of the upper conductive layer and the lower conductive layer is a transparent conductive layer, and the other one of the upper conductive layer and the lower conductive layer is a reflective conductive layer.

10. The liquid crystal display device of claim 1, wherein:

the at least one first opening of the upper conductive layer includes a plurality of first opening; and

a plurality of liquid crystal domains are formed in response to a voltage applied between the first electrode and the second electrode, each of the plurality of liquid crystal domains being formed in the liquid crystal layer corresponding to respective one of the first openings provided in the first electrode, and having a radially-inclined orientation.

11. The liquid crystal display device of claim 10, wherein the second substrate further includes an orientation-regulating structure in a region corresponding to at least one of the plurality of liquid crystal domains, the orientation-regulating structure exerting an orientation-regulating force for orienting liquid crystal molecules in the at least one liquid crystal domain into a radially-inclined orientation at least in the presence of an applied voltage.

12. The liquid crystal display device of claim 11, wherein the orientation-regulating structure is provided in a region corresponding to a region in the vicinity of a center of the at least one liquid crystal domain.

13. The liquid crystal display device of claim 11, wherein in the at least one liquid crystal domain, a direction of orientation regulation by the orientation-regulating structure coincides with a direction of the radially-inclined orientation.

14. The liquid crystal display device of claim 11, wherein the orientation-regulating structure exerts an orientation-regulating force for orienting the liquid crystal molecules into a radially-inclined orientation even in the absence of an applied voltage.

15. The liquid crystal display device of claim 14, wherein the orientation-regulating structure is a protrusion protruding from the second substrate into the liquid crystal layer.

16. The liquid crystal display device of claim 14, wherein the orientation-regulating structure includes a surface having a horizontal alignment power provided on one side of the second substrate which is closer to the liquid crystal layer.

17. The liquid crystal display device of claim 11, wherein the orientation-regulating structure exerts an orientation-regulating force for orienting the liquid crystal molecules into a radially-inclined orientation only in the presence of an applied voltage.

18. The liquid crystal display device of claim 17, wherein the orientation-regulating structure includes an opening provided in the second electrode.

19. The liquid crystal display device of claim 1, further comprising a pair of polarizing plates provided so as to oppose each other via the liquid crystal layer, wherein the pair of polarizing plates are arranged in a crossed-Nicols state.

20. The liquid crystal display device of claim 19, further comprising a pair of quarter-wave plates provided so as to oppose each other via the liquid crystal layer, wherein each of the pair of quarter-wave plates is provided between the liquid crystal layer and a respective one of the pair of polarizing plates.

21. The liquid crystal display device of claim 20, further comprising a pair of half-wave plates provided so as to oppose each other via the liquid crystal layer, wherein each of the pair of half-wave plates is provided between a respective one of the pair of polarizing plates and a respective one of the pair of quarter-wave plates.

22. The liquid crystal display device of claim 20, wherein slow axes of the pair of quarter-wave plates are arranged so as to be perpendicular to each other.

23. The liquid crystal display device of claim 20, wherein slow axes of the pair of half-wave plates are arranged so as to be perpendicular to each other.

24. The liquid crystal display device of claim 20, wherein the liquid crystal layer in each of the plurality of picture element regions takes a spiral orientation in response to a voltage applied between the first electrode and the second electrode.

25. The liquid crystal display device of claim 24, wherein the liquid crystal layer in each of the plurality of picture element regions includes a minute region which takes a twist orientation along the liquid crystal layer in response to the voltage applied between the first electrode and the second electrode.

26. The liquid crystal display device of claim 1, wherein:

the first substrate further includes an active element for each of the plurality of picture element regions; and

the first electrode is a picture element electrode which is provided for each of the plurality of picture element regions and is switched by the active element, and the second electrode is at least one counter electrode opposing the plurality of picture element regions.

27. A liquid crystal display device, comprising:

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

a plurality of picture element regions each defined by a first electrode provided on one side of the first substrate which is closer to the liquid crystal layer and a second electrode provided on the second substrate so as to oppose the first electrode via the liquid crystal layer, wherein:

the first electrode includes a lower conductive layer, a dielectric layer covering at least a portion of the lower conductive layer, and an upper conductive layer provided on one side of the dielectric layer which is closer to the liquid crystal layer; and in each of the plurality of picture element regions, the upper conductive layer includes a plurality of openings and a solid portion, the liquid crystal layer taking a vertical alignment in the absence of an applied voltage between the first electrode and the second electrode, a plurality of liquid crystal domains being formed in the plurality of openings or in the solid portion by inclined electric fields produced at respective edge portions of the plurality of openings of the upper conductive layer in response to a voltage applied between the first electrode and the second electrode, each of the plurality of liquid crystal domains taking a radially-inclined orientation, and an orientation of each of the plurality of liquid crystal domains changing according to the applied voltage, thereby producing a display.

28. The liquid crystal display device of claim 27, wherein at least some of the plurality of openings have substantially the same shape and substantially the same size, and form at least one unit lattice arranged so as to have rotational symmetry.

29. The liquid crystal display device of claim 28, wherein a shape of each of the at least some of the plurality of openings has rotational symmetry.

30. The liquid crystal display device of claim 28, wherein each of the at least some of the plurality of openings has a generally circular shape.

31. The liquid crystal display device of claim 28, wherein the solid portion includes a plurality of unit solid portions each of which is substantially surrounded by the at least one opening, and each of the plurality of unit solid portions has a generally circular shape.

32. The liquid crystal display device of claim 27, wherein in each of the plurality of picture element regions, a total area of the plurality of openings of the first electrode is smaller than an area of the solid portion of the first electrode.

33. The liquid crystal display device of claim 27, further comprising a protrusion within each of the plurality of openings, the protrusion having the same cross-sectional shape in a plane of the first substrate as that of the plurality of openings, a side surface of the protrusion having an orientation-regulating force of the same direction with respect to liquid crystal molecules of the liquid crystal layer as a direction of orientation regulation by the inclined electric field.

34. The liquid crystal display device of claim 27, wherein:

the first substrate further includes an active element provided for each of the plurality of picture element regions; and

the first electrode is a picture element electrode which is provided for each of the plurality of picture element regions and is switched by the active element, and the second electrode is at least one counter electrode opposing the plurality of picture element regions.

35. A liquid crystal display device, comprising:

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

a plurality of picture element regions each defined by a first electrode provided on one side of the first substrate which is closer to the liquid crystal layer and a second electrode provided on the second substrate so as to oppose the first electrode via the liquid crystal layer, wherein:

in each of the plurality of picture element regions, the liquid crystal layer takes a vertical alignment in the absence of an applied voltage between the first electrode and the second electrode, and changes its orientation according to a voltage applied between the first electrode and the second electrode;

the first electrode includes a lower conductive layer, a first dielectric layer including a first opening, a second dielectric layer provided on the lower conductive layer and the first dielectric layer, and an upper conductive layer provided on one side of the second dielectric layer which is closer to the liquid crystal layer; and

the upper conductive layer includes at least one conductive layer opening, the lower conductive layer being provided so as to oppose at least a portion of the at least one conductive layer opening via the second dielectric layer, the first opening being provided so as to correspond to the conductive layer opening, and a height of a surface of the second dielectric layer being smaller in the conductive layer opening than in a region where the upper conductive layer is provided.

36. The liquid crystal display device of claim 35, wherein the first dielectric layer is provided on the lower conductive layer, and the first opening is formed so as to expose a portion of the lower conductive layer.

37. The liquid crystal display device of claim 35, wherein the first dielectric layer is provided under the lower conductive layer, and the lower conductive layer is provided so as to cover the first opening.

38. The liquid crystal display device of claim 35, wherein the first substrate further includes a third dielectric layer under the lower conductive layer, and the third dielectric layer includes a second opening in a region corresponding to the conductive layer opening.

39. The liquid crystal display device of claim 38, wherein the first substrate further includes a thin film transistor, and the third dielectric layer also functions as a gate insulating film of the thin film transistor.

40. A method for producing a liquid crystal display device, the liquid crystal display device comprising a first substrate, a second substrate, a liquid crystal layer provided between the first substrate and the second substrate, and a plurality of picture element regions each defined by a first electrode provided on one side of the first substrate which is closer to the liquid crystal layer and a second electrode provided on the second substrate so as to oppose the first electrode via the liquid crystal layer, wherein:

the first electrode includes a lower conductive layer, a first dielectric layer including a first opening, a second dielectric layer provided on the lower conductive layer and the first dielectric layer, and an upper conductive layer provided on one side of the second dielectric layer which is closer to the liquid crystal layer; and

the upper conductive layer includes at least one conductive layer opening, the lower conductive layer being provided so as to oppose at least a portion of the at least one conductive layer opening via the second dielectric layer, the step of providing the first electrode comprising the steps of:

providing a lower conductive layer on a substrate;

providing a first dielectric layer including a first opening on the substrate;

providing a second dielectric layer on the lower conductive layer and the first dielectric layer, wherein a height of the second dielectric layer is greater in a region corresponding to the first opening than in other regions; and

providing an upper conductive layer including a conductive layer opening on the second dielectric layer in the region corresponding to the first opening.

41. The method for producing a liquid crystal display device of claim 40, wherein the first dielectric layer is provided on the lower conductive layer so that the lower conductive layer is exposed through the first opening.

42. The method for producing a liquid crystal display device of claim 40, wherein the lower conductive layer is provided on the first dielectric layer so as to cover at least the first opening of the first dielectric layer.

43. The method for producing a liquid crystal display device of claim 40, further comprising, before the step of providing the lower conductive layer, the step of providing a third dielectric layer including a second opening on the substrate.

44. The method for producing a liquid crystal display device of claim 43, further comprising the step of providing a thin film transistor on the substrate, wherein the third dielectric layer is provided so as to also function as a gate insulating film of the thin film transistor.

45. A method for producing a liquid crystal display device, the liquid crystal display device comprising a first substrate, a second substrate, a liquid crystal layer provided between the first substrate and the second substrate, and a plurality of picture element regions each defined by a first electrode provided on one side of the first substrate which is closer to the liquid crystal layer and a second electrode provided on the second substrate so as to oppose the first electrode via the liquid crystal layer, wherein:

the first electrode includes a lower conductive layer, a dielectric layer covering at least a portion of the lower conductive layer, and an upper conductive layer provided on one side of the dielectric layer which is closer to the liquid crystal layer; and

the upper conductive layer includes at least one conductive layer opening, and the lower conductive layer is provided so as to oppose at least a portion of the at least one conductive layer opening via the dielectric layer, the step of providing the first electrode comprising the steps of:

providing a lower conductive layer on a substrate;

providing a dielectric film on the lower conductive layer;

providing an upper conductive layer including a conductive layer opening on the dielectric film; and

partially removing a dielectric film in the conductive layer opening using the upper conductive layer as a mask so as to provide a dielectric layer, wherein a height of a surface of the dielectric layer is smaller in a region corresponding to the conductive layer opening than in other regions.

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外部链接	Espacenet USPTO		

摘要(译)

本发明提供一种具有高显示质量的液晶显示装置。液晶显示装置通过第一电极和第二电极施加电压来显示图像，该液晶层在没有施加电压的情况下进行垂直取向。第一电极包括下导电层，覆盖下导电层的至少一部分的介电层，以及设置在介电层的靠近液晶层的一侧上的上导电层。上导电层包括第一开口，并且下导电层设置为经由介电层与第一开口的至少一部分相对。

FIG. 1A

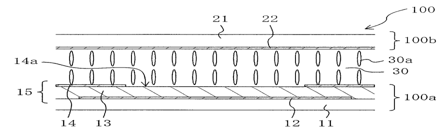

FIG. 1B

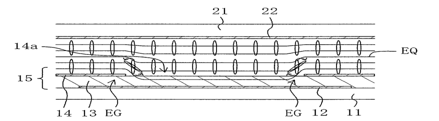

FIG. 1C