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(54) **LIQUID CRYSTAL DISPLAY DEVICE**

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G02F 1/1333 (2006.01)
G02F 1/1337 (2006.01)

(52) **U.S. Cl.**

CPC *G02F 1/134363* (2013.01); *G02F 1/1337* (2013.01); *G02F 1/133345* (2013.01)

(57) **ABSTRACT**

A liquid crystal display device of the present invention includes, in the given order: a first substrate; a liquid crystal layer containing liquid crystal molecules; and a second substrate. The first substrate includes a first electrode, a second electrode closer to the liquid crystal layer than the first electrode is, and an insulating film between the first electrode and the second electrode. The second electrode is provided with openings including a first opening and a second opening adjacent to each other. The first opening and the second opening are independent of each other and are point-symmetrical to each other. The first opening and the second opening each have a shape including: curved portions that expand an opening periphery outward at the respective ends in the longitudinal direction; and paired protruding portions that allow the opening periphery to protrude partially in the lateral direction in the middle of the longitudinal direction. The liquid crystal molecules are aligned parallel to the first substrate in a no-voltage-applied state where no voltage is applied between the first electrode and the second electrode.

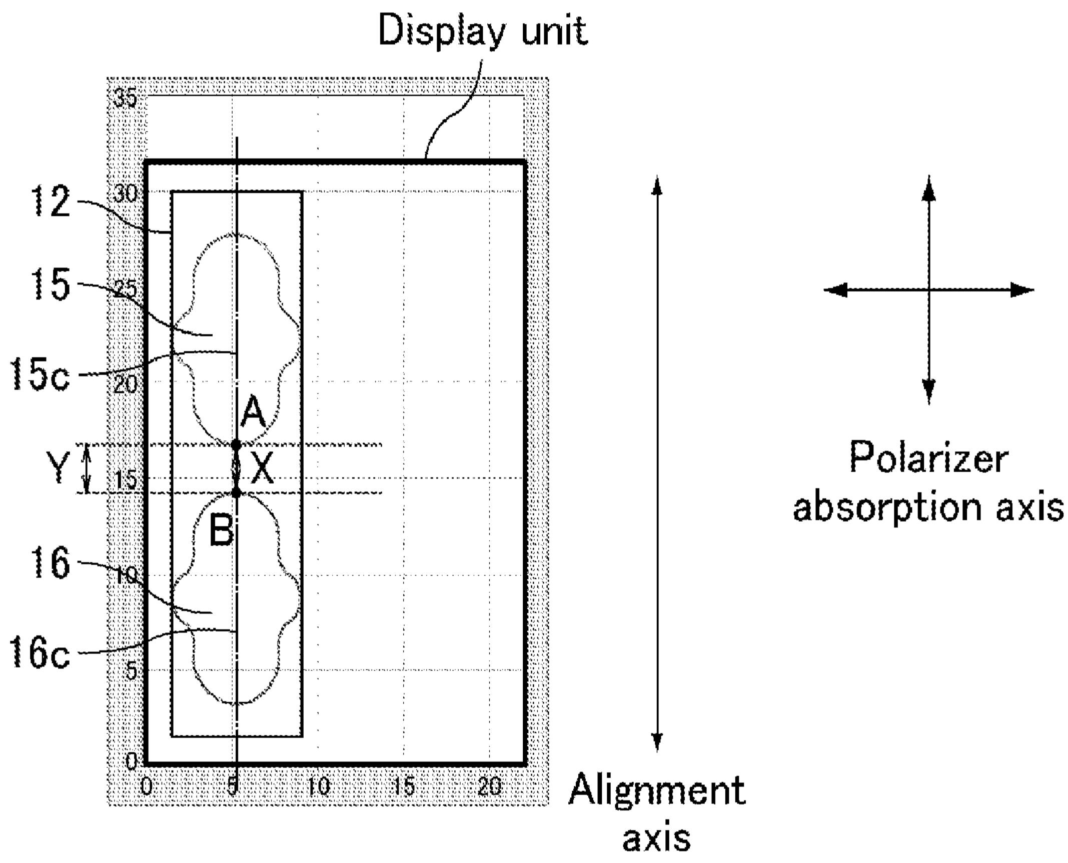


Fig. 1

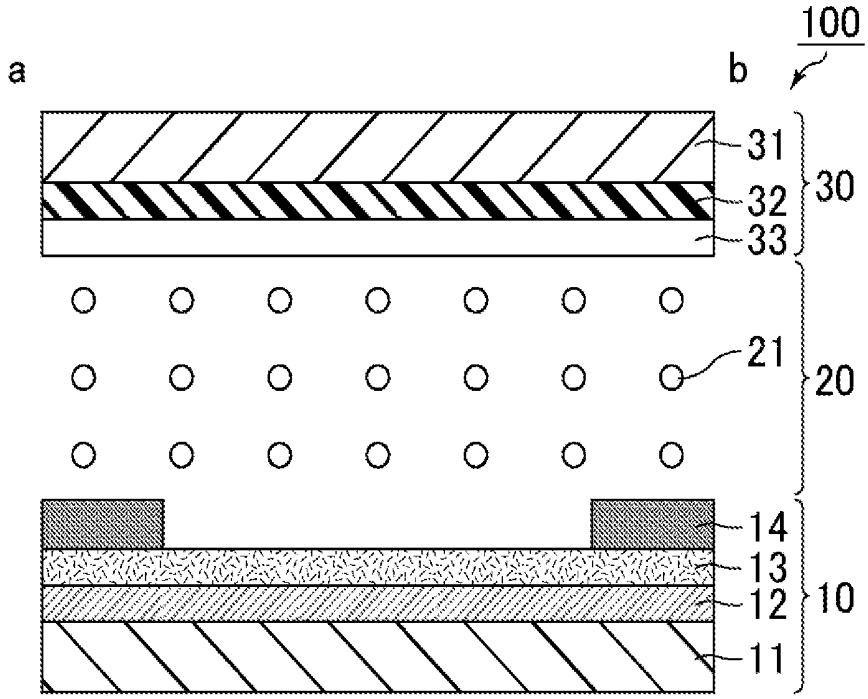

100
a
b
31
32
30
33
21
20
14
13
12
10
11

Fig. 2

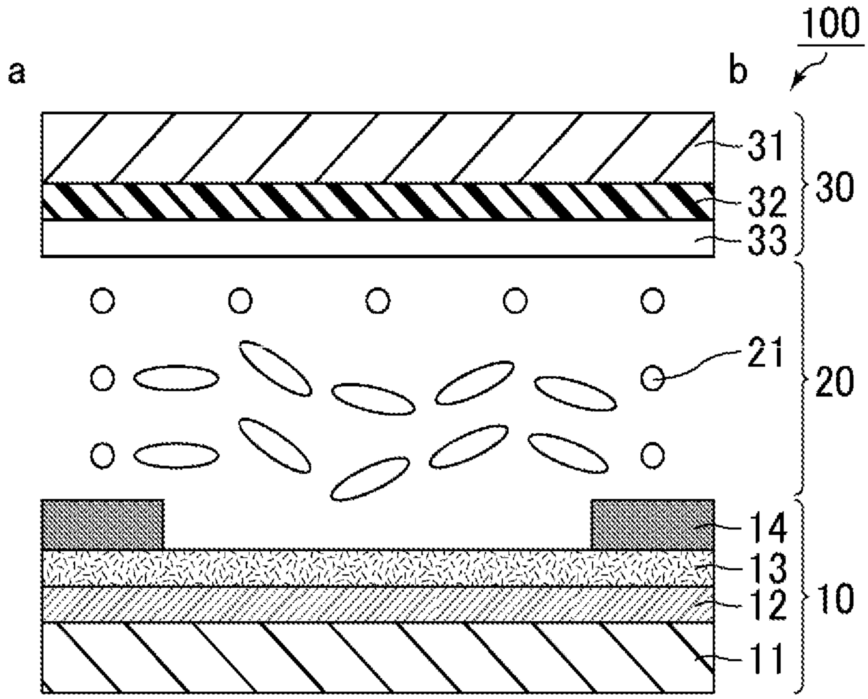

100
a
b
31
32
30
33
21
20
14
13
12
10
11

Fig. 3

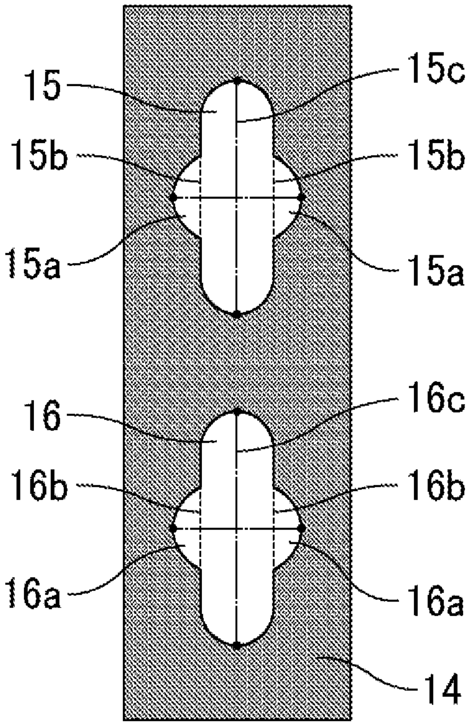


Fig. 4

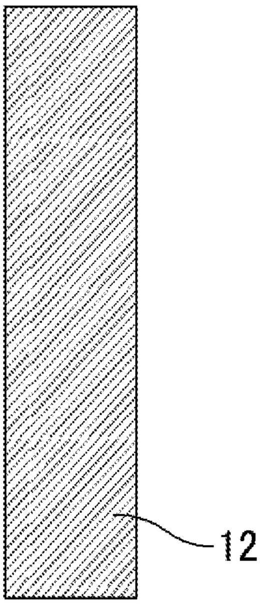


Fig. 5

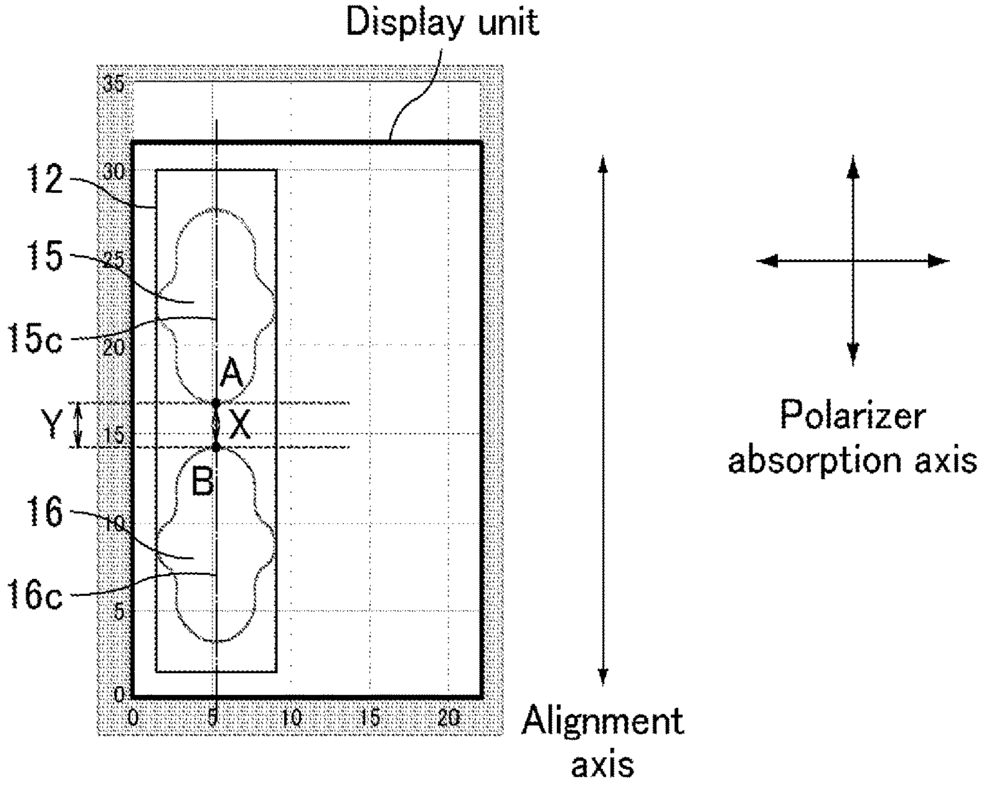

Display unit
12
15
15c
A
Y
X
B
16
16c
Alignment axis
Polarizer absorption axis
0
5
10
15
20
25
30
35

Fig. 6

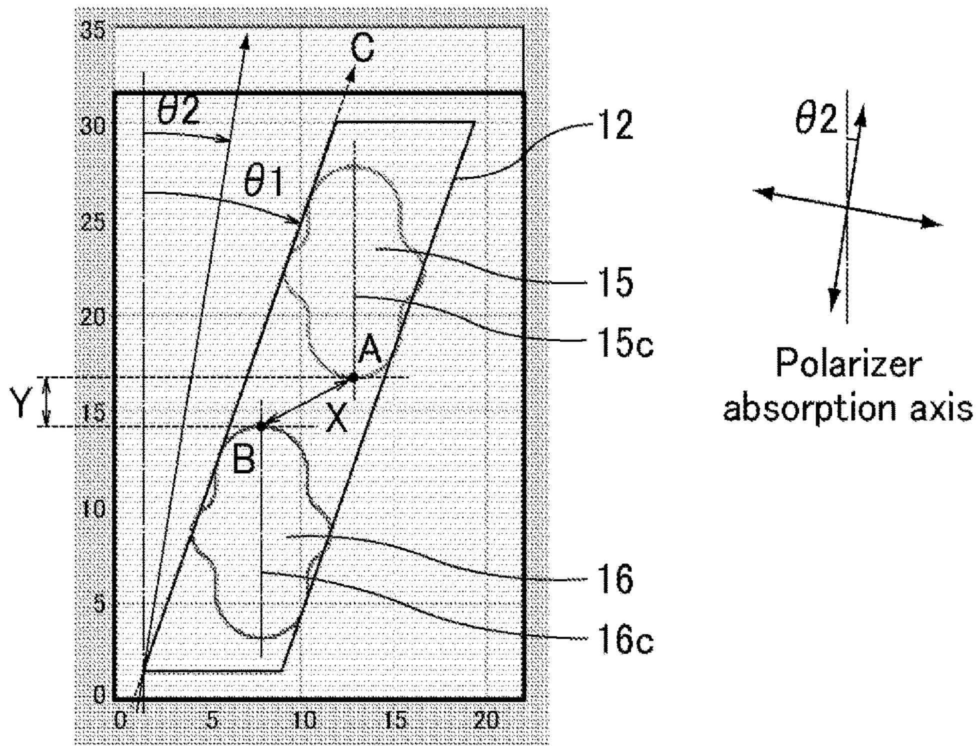

C
θ2
θ1
12
15
15c
A
Y
X
B
16
16c
θ2
Polarizer absorption axis
0
5
10
15
20
25
30
35

Fig. 7

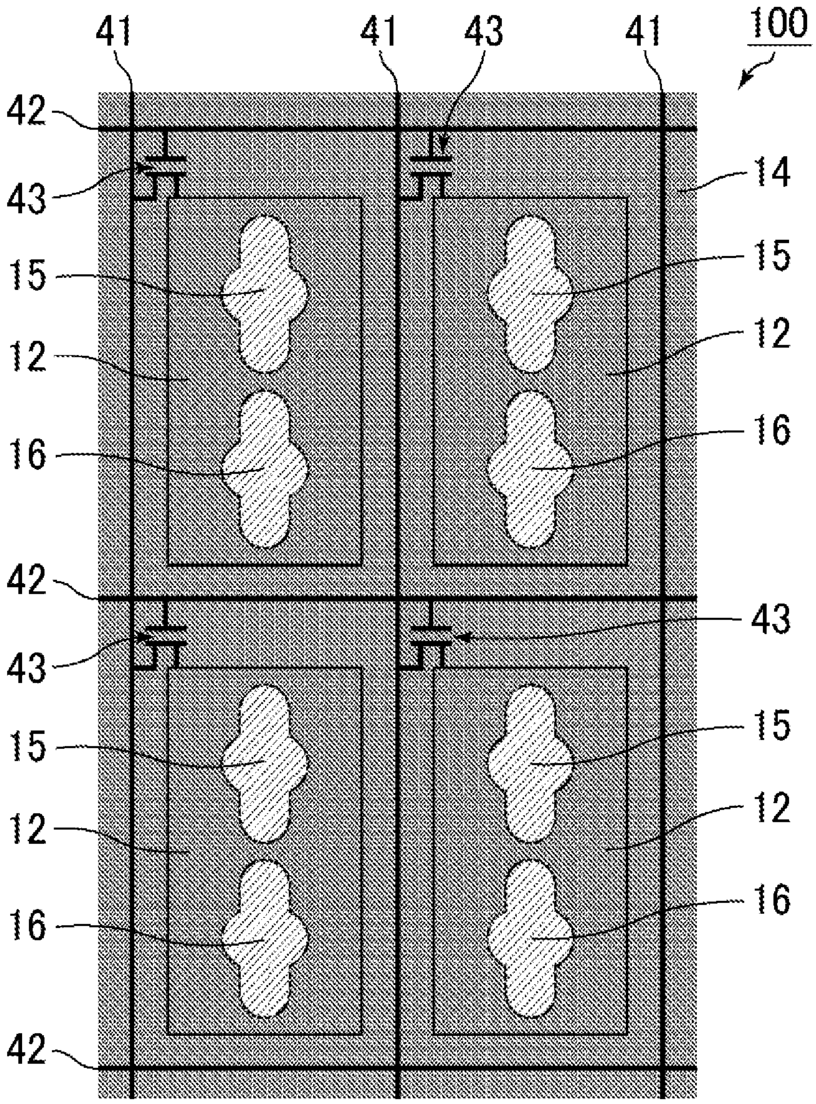


Fig. 8

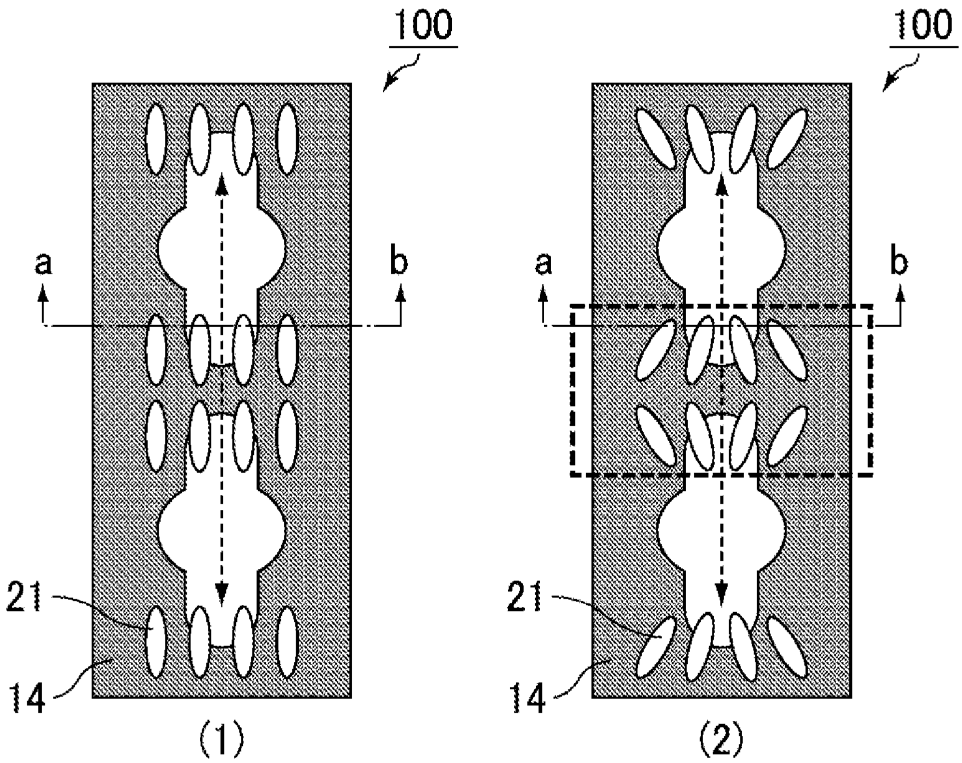


Fig. 9

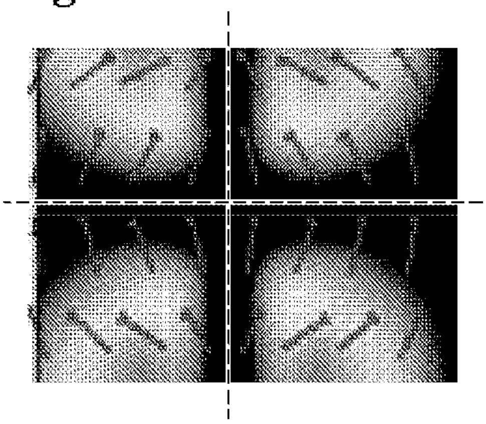


Fig. 10

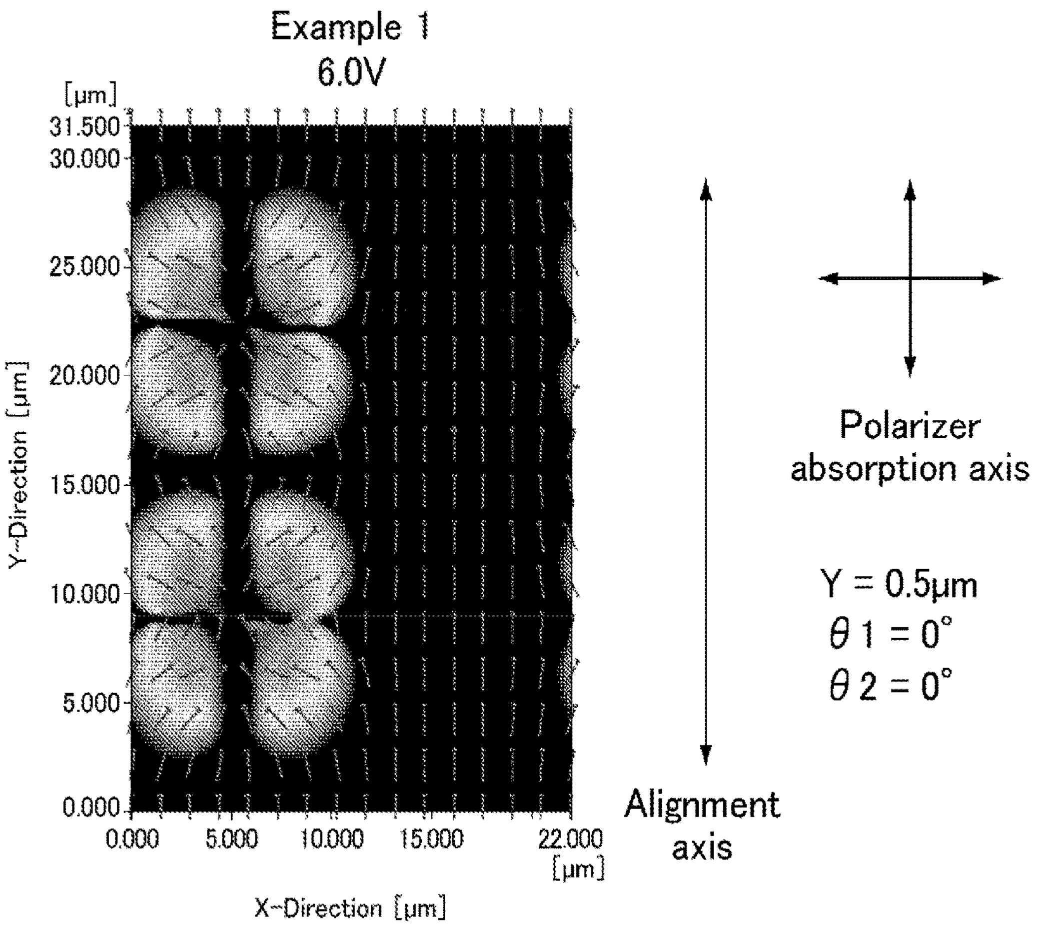

Example 1
6.0V
[μm]
31.500
30.000
25.000
20.000
15.000
10.000
5.000
0.000
Y-Direction [μm]
0.000
5.000
10.000
15.000
22.000
[μm]
X-Direction [μm]
Alignment axis
Polarizer absorption axis
Y = 0.5μm
θ1 = 0°
θ2 = 0°

Fig. 11

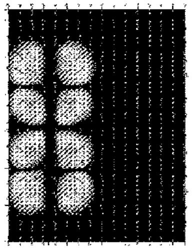
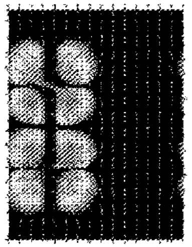
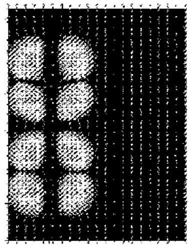
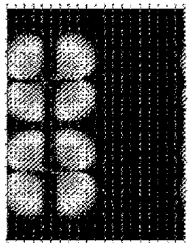
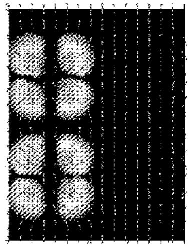
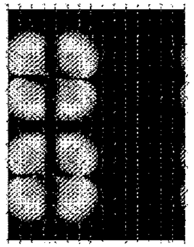
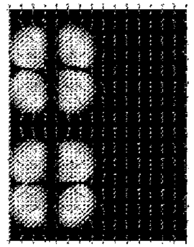
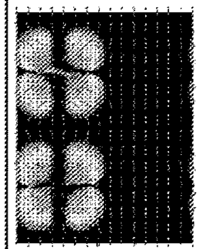
	Example 1		Example 2		Example 3		Example 4	
Y(μm)	0.5		1.5		2.5		4.5	
θ1(°)	0		0		0		0	
θ2(°)	0		0		0		0	
Applied voltage	5.0V	6.0V	5.0V	6.0V	5.0V	6.0V	5.0V	6.0V
Photograph								
Evaluation	Fair	Fair	Excellent	Excellent	Good	Fair	Fair	Fair

Fig. 12

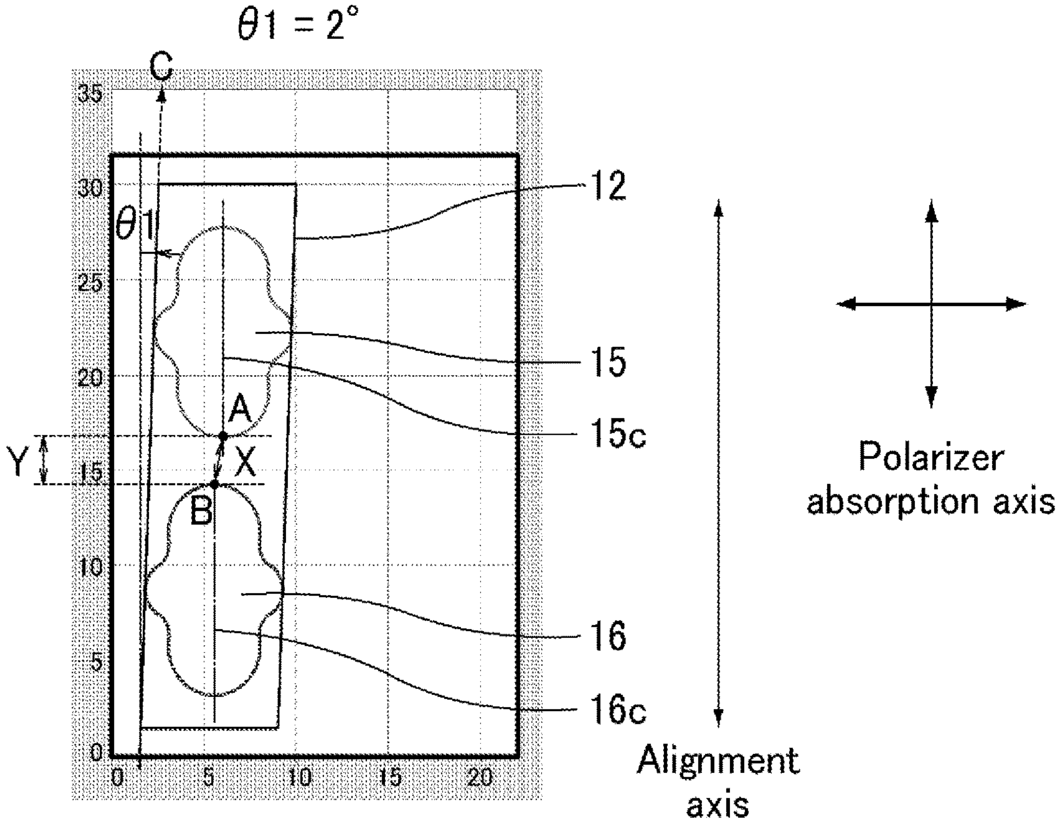

θ1 = 2°
C
35
30
25
20
15
10
5
0
0
5
10
15
20
θ1
A
X
B
Y
12
15
15c
16
16c
Alignment axis
Polarizer absorption axis

Fig. 13

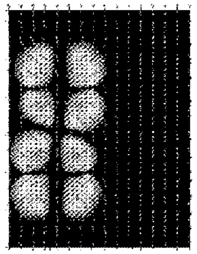
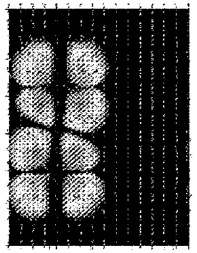
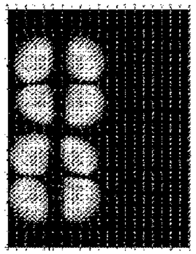
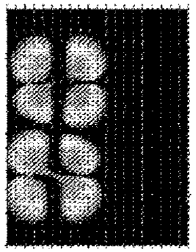
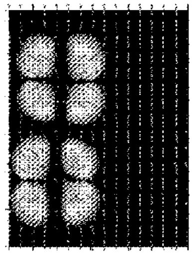
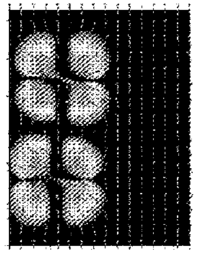
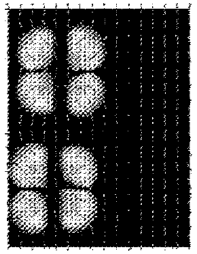
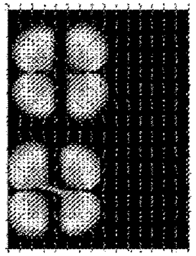
	Example 5		Example 6		Example 7		Example 8	
Y(μm)	0.5		1.5		2.5		4.5	
θ1(°)	2		2		2		2	
θ2(°)	0		0		0		0	
Applied voltage	5.0V	6.0V	5.0V	6.0V	5.0V	6.0V	5.0V	6.0V
Photograph								
Evaluation	Fair	Fair	Excellent	Excellent	Excellent	Good	Fair	Fair

Fig. 14

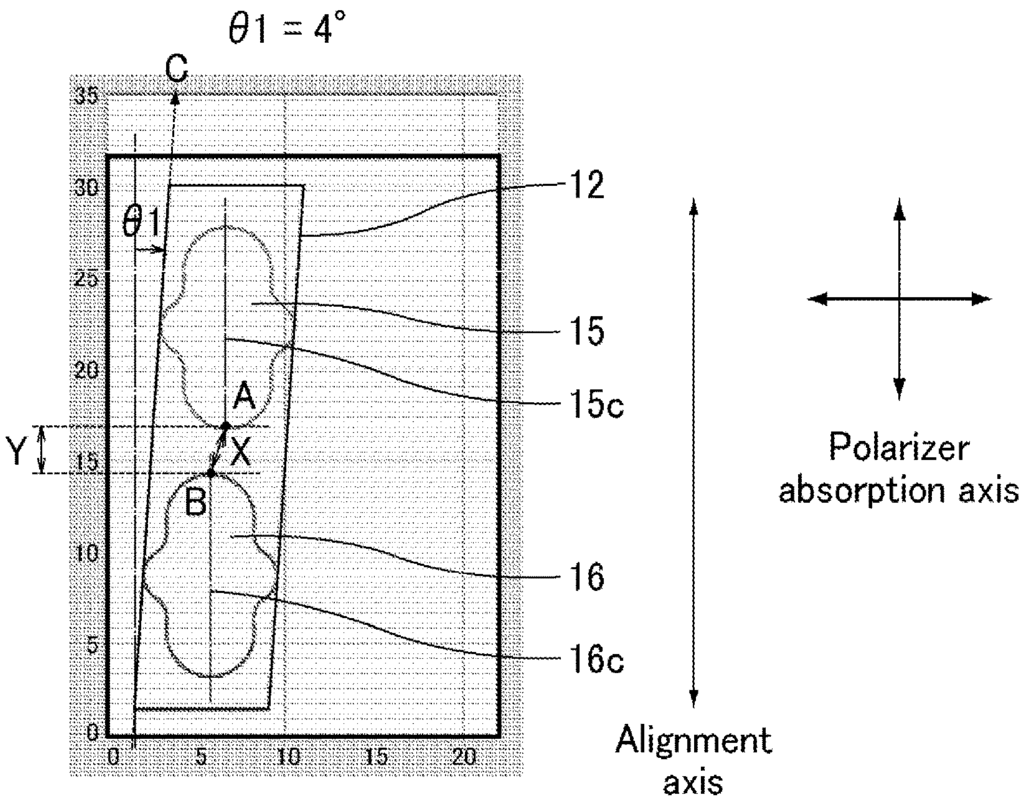

θ1 = 4°
C
θ1
35
30
25
20
15
10
5
0
0
5
10
15
20
A
B
X
Y
12
15
15c
16
16c
Alignment axis
Polarizer absorption axis

Fig. 15

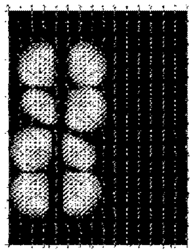
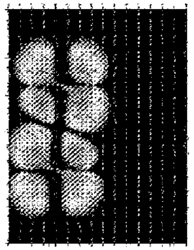
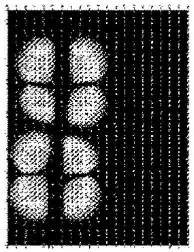
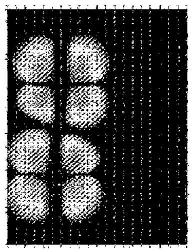
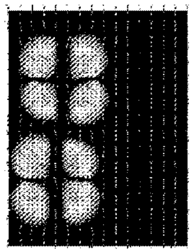
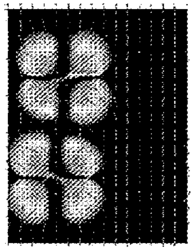
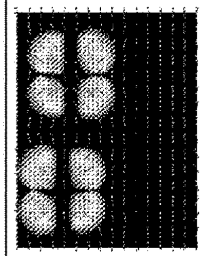
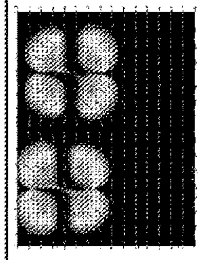
	Example 9		Example 10		Example 11		Example 12	
Y(μm)	0.5		1.5		2.5		4.5	
θ1(°)	4		4		4		4	
θ2(°)	0		0		0		0	
Applied voltage	5.0V	6.0V	5.0V	6.0V	5.0V	6.0V	5.0V	6.0V
Photograph								
Evaluation	Good	Fair	Excellent	Good	Excellent	Good	Fair	Fair

Fig. 16

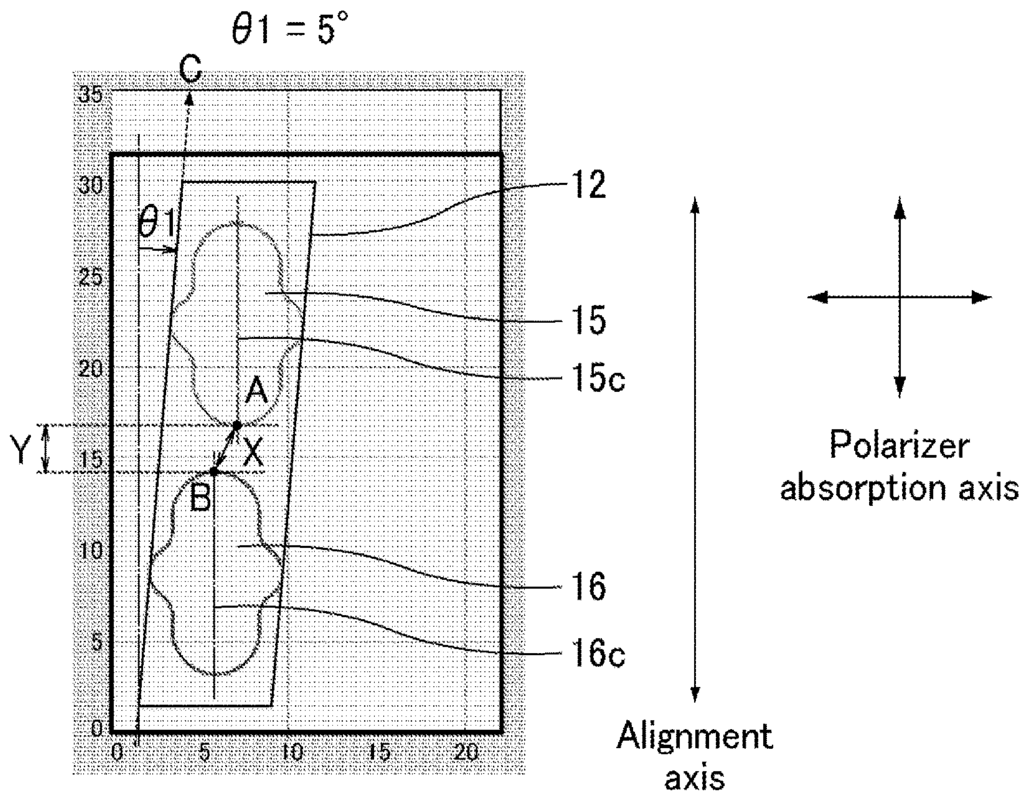

θ1 = 5°
C
θ1
A
B
X
Y
12
15
15c
16
16c
Alignment axis
Polarizer absorption axis
0
5
10
15
20
25
30
35

Fig. 17

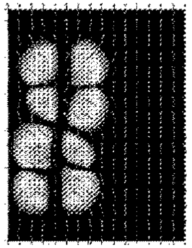
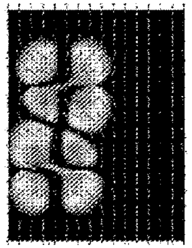
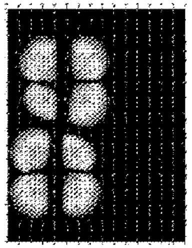
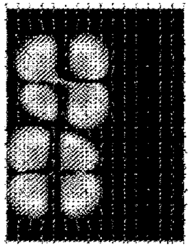
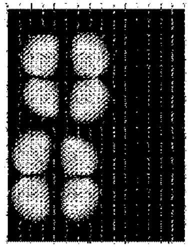
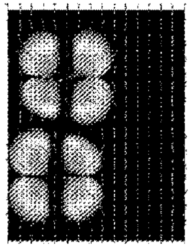
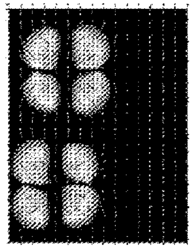
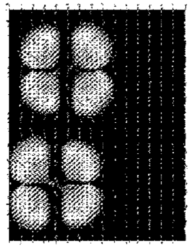
	Example 13		Example 14		Example 15		Example 16	
Y(μm)	0.5		1.5		2.5		4.5	
θ1(°)	5		5		5		5	
θ2(°)	0		0		0		0	
Applied voltage	5.0V	6.0V	5.0V	6.0V	5.0V	6.0V	5.0V	6.0V
Photograph								
Evaluation	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Fair	Fair

Fig. 18

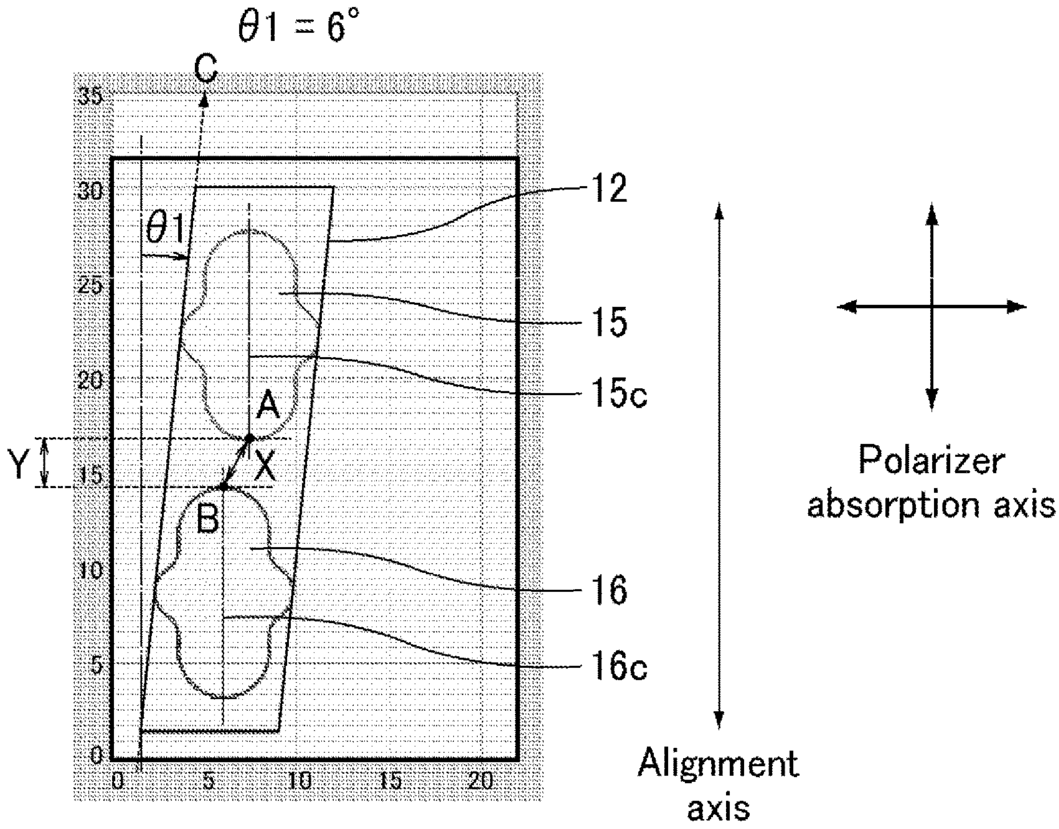

$\theta 1 = 6°$
C
35
30
25
20
15
10
5
0
0
5
10
15
20
$\theta 1$
A
X
Y
B
12
15
15c
16
16c
Alignment axis
Polarizer absorption axis

Fig. 19

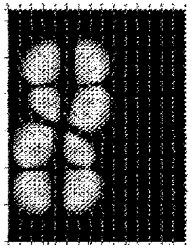
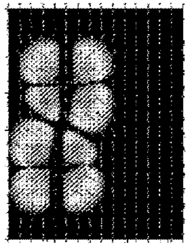
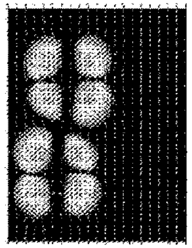
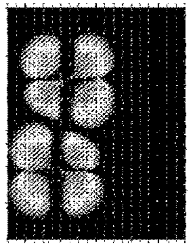
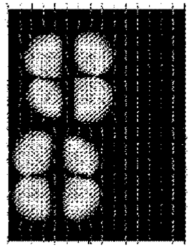
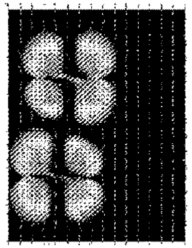
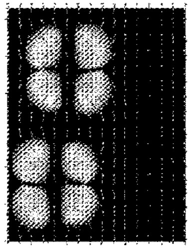
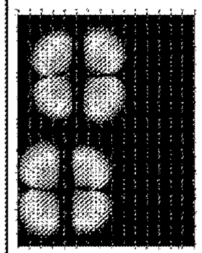
	Example 17		Example 18		Example 19		Example 20	
Y(μm)	0.5		1.5		2.5		4.5	
θ1(°)	6		6		6		6	
θ2(°)	0		0		0		0	
Applied voltage	5.0V	6.0V	5.0V	6.0V	5.0V	6.0V	5.0V	6.0V
Photograph								
Evaluation	Excellent	Excellent	Excellent	Excellent	Excellent	Good	Good	Good

Fig. 20

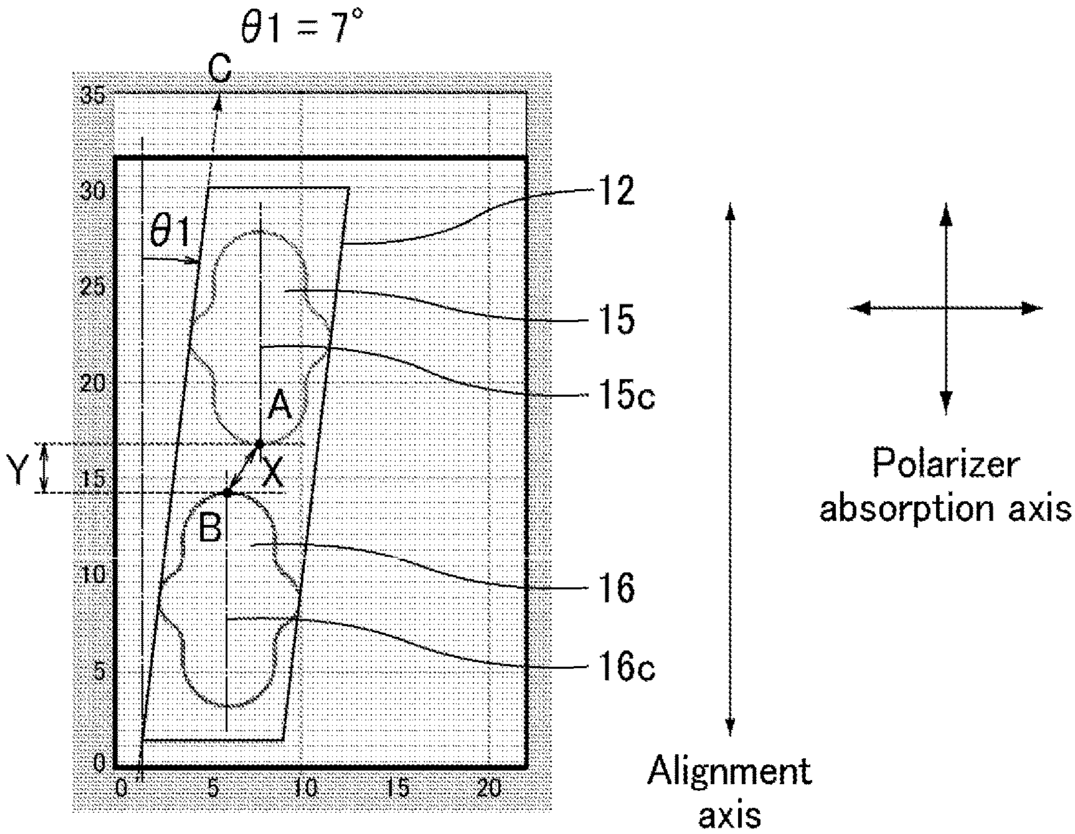

θ1 = 7°
C
35
30
25
20
15
10
5
0
0
5
10
15
20
θ1
A
X
B
Y
12
15
15c
16
16c
Alignment
axis
Polarizer
absorption axis

Fig. 21

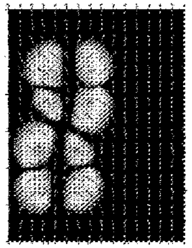
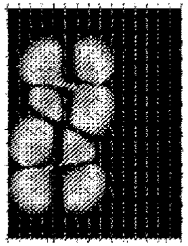
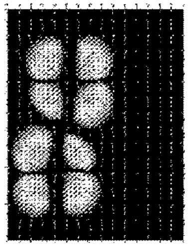
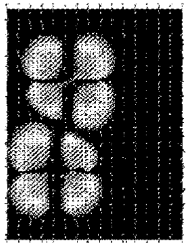
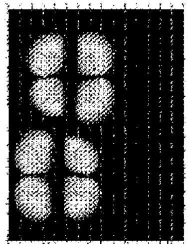
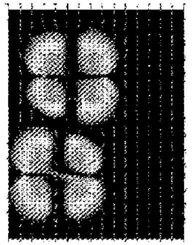
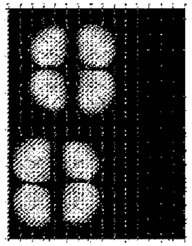
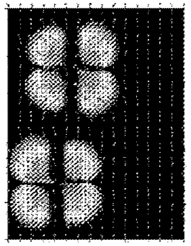
	Example 21		Example 22		Example 23		Example 24	
Y(μm)	0.5		1.5		2.5		4.5	
θ1(°)	7		7		7		7	
θ2(°)	0		0		0		0	
Applied voltage	5.0V	6.0V	5.0V	6.0V	5.0V	6.0V	5.0V	6.0V
Photograph								
Evaluation	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Good	Fair

Fig. 22

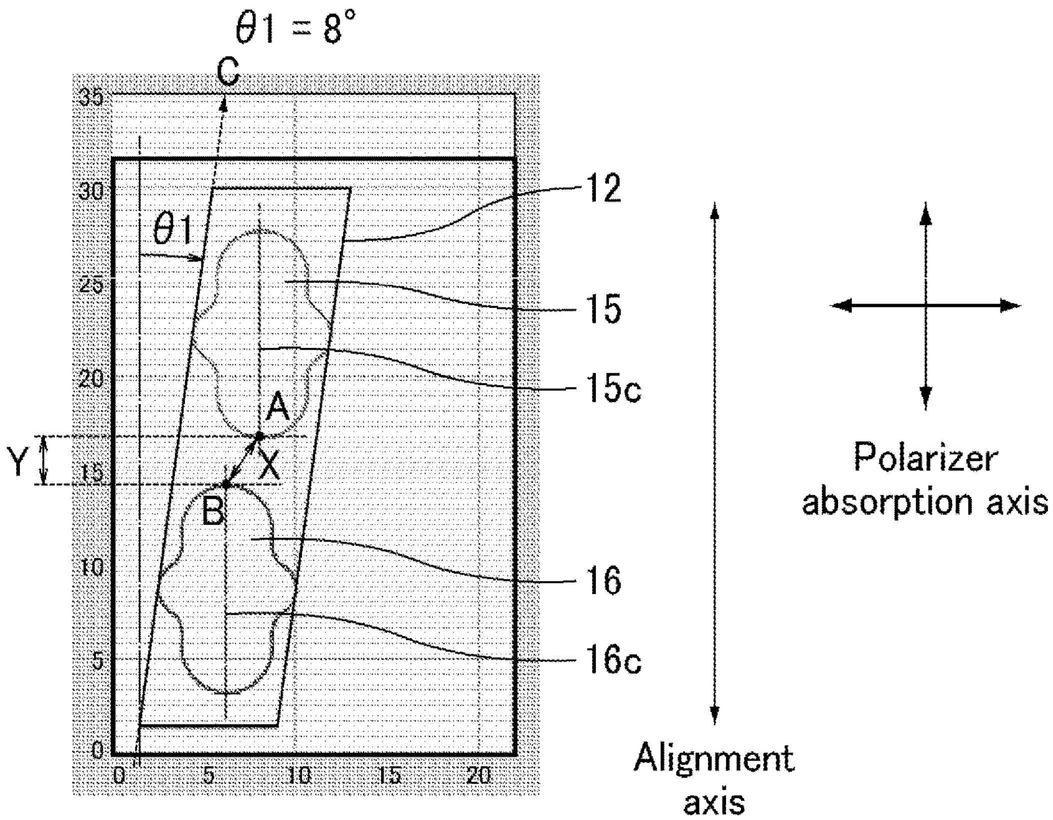

θ1 = 8°
C
θ1
A
X
Y
B
35
30
25
20
15
10
5
0
0
5
10
15
20
12
15
15c
16
16c
Alignment axis
Polarizer absorption axis

Fig. 23

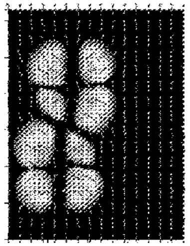
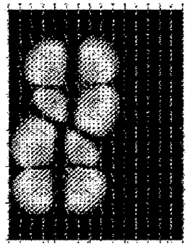
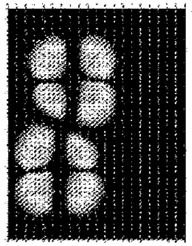
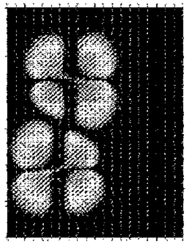
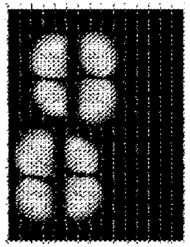
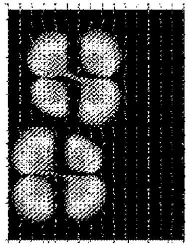
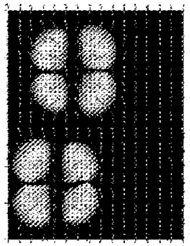
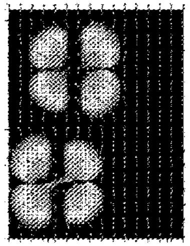
	Example 25		Example 26		Example 27		Example 28	
Y(μm)	0.5		1.5		2.5		4.5	
θ1(°)	8		8		8		8	
θ2(°)	0		0		0		0	
Applied voltage	5.0V	6.0V	5.0V	6.0V	5.0V	6.0V	5.0V	6.0V
Photograph								
Evaluation	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Good	Good

Fig. 24

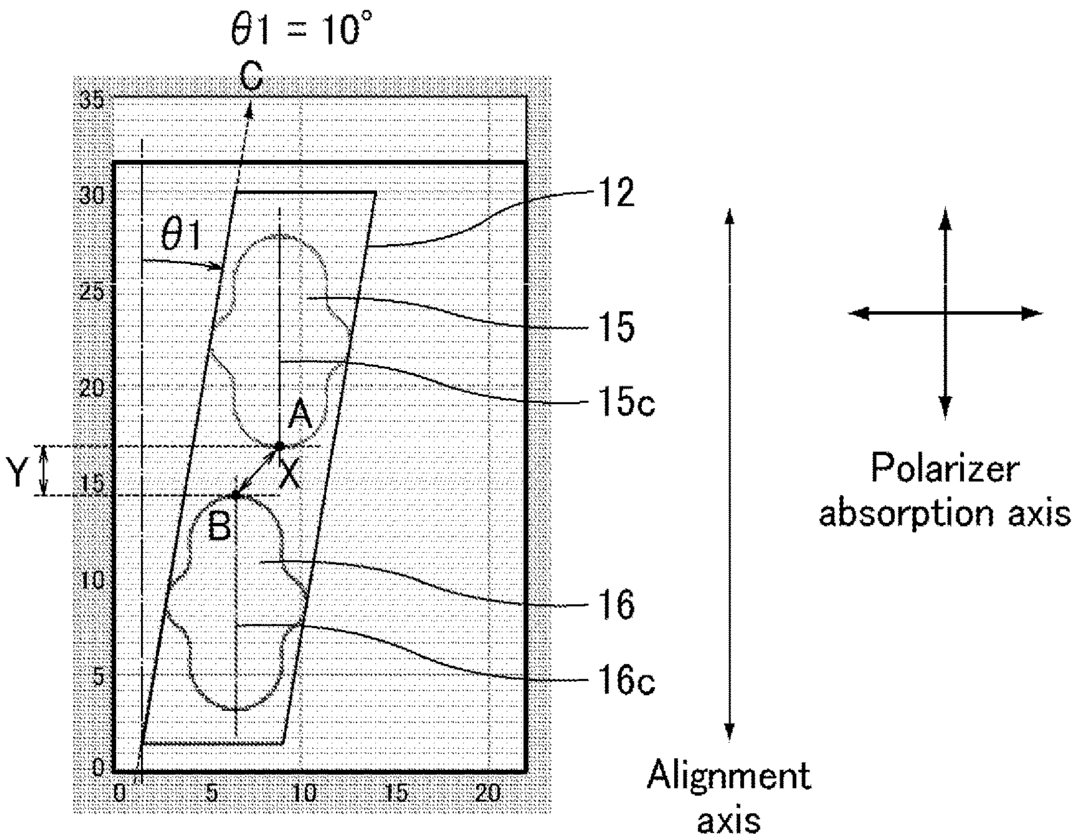

θ1 = 10°
C
θ1
A
X
Y
B
12
15
15c
16
16c
0
5
10
15
20
25
30
35
Alignment axis
Polarizer absorption axis

Fig. 25

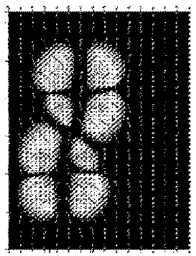
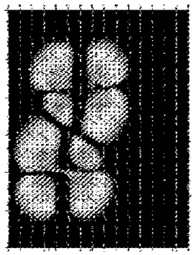
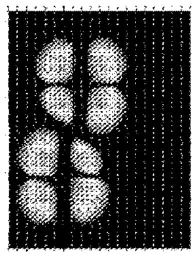
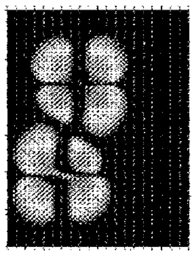
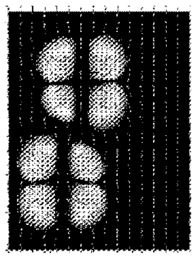
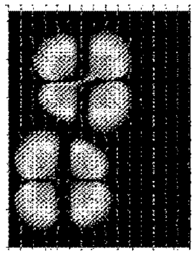
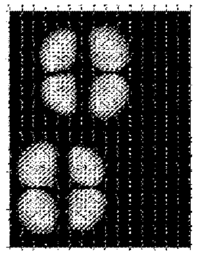
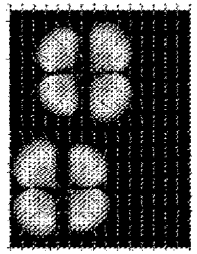
	Example 29		Example 30		Example 31		Example 32	
Y(μm)	0.5		1.5		2.5		4.5	
θ1(°)	10		10		10		10	
θ2(°)	0		0		0		0	
Applied voltage	5.0V	6.0V	5.0V	6.0V	5.0V	6.0V	5.0V	6.0V
Photograph								
Evaluation	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent

Fig. 26

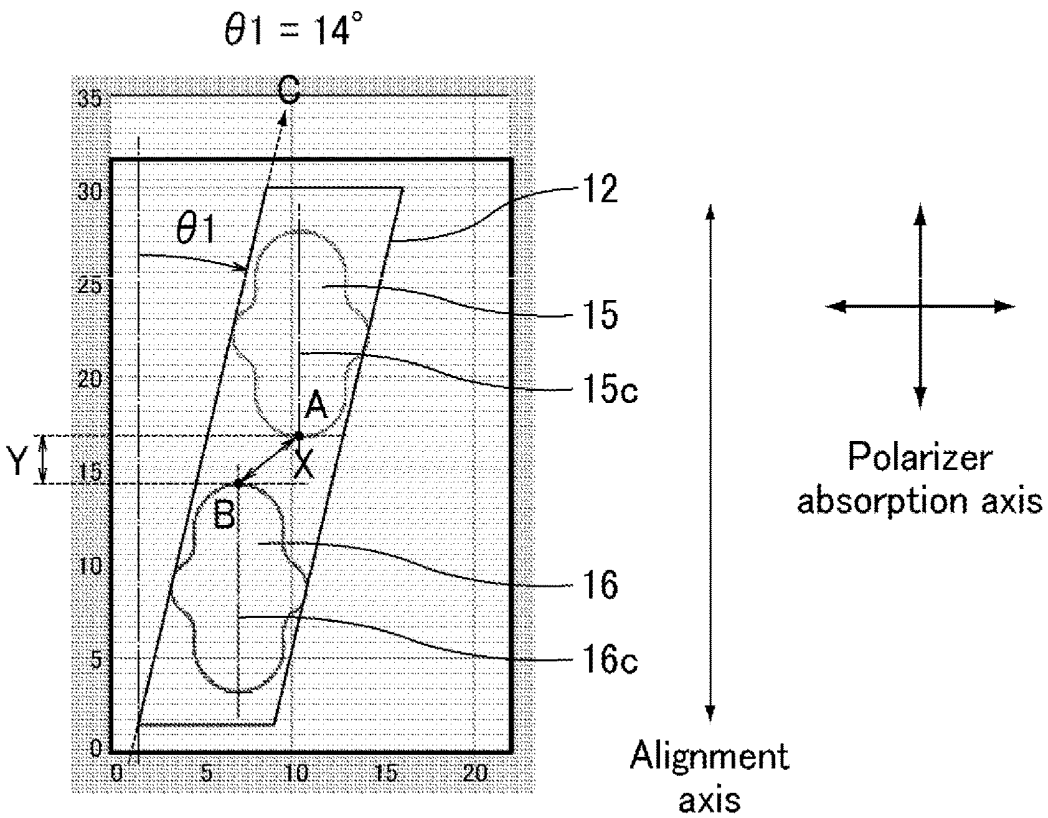

θ1 = 14°
C
θ1
A
X
Y
B
35
30
25
20
15
10
5
0
0
5
10
15
20
12
15
15c
16
16c
Alignment axis
Polarizer absorption axis

Fig. 27

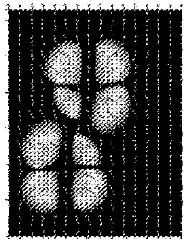
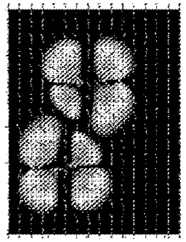
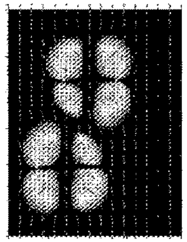
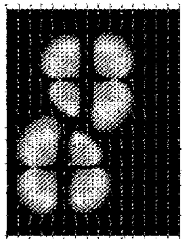
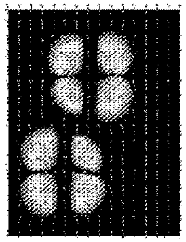
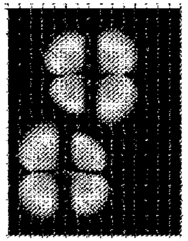
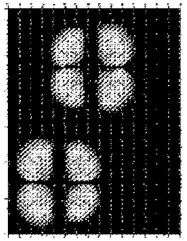
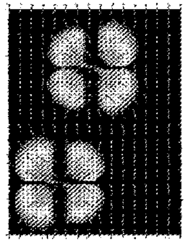
	Example 33		Example 34		Example 35		Example 36	
Y(μm)	0.5		1.5		2.5		4.5	
θ1(°)	14		14		14		14	
θ2(°)	0		0		0		0	
Applied voltage	5.0V	6.0V	5.0V	6.0V	5.0V	6.0V	5.0V	6.0V
Photograph								
Evaluation	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent

Fig. 28

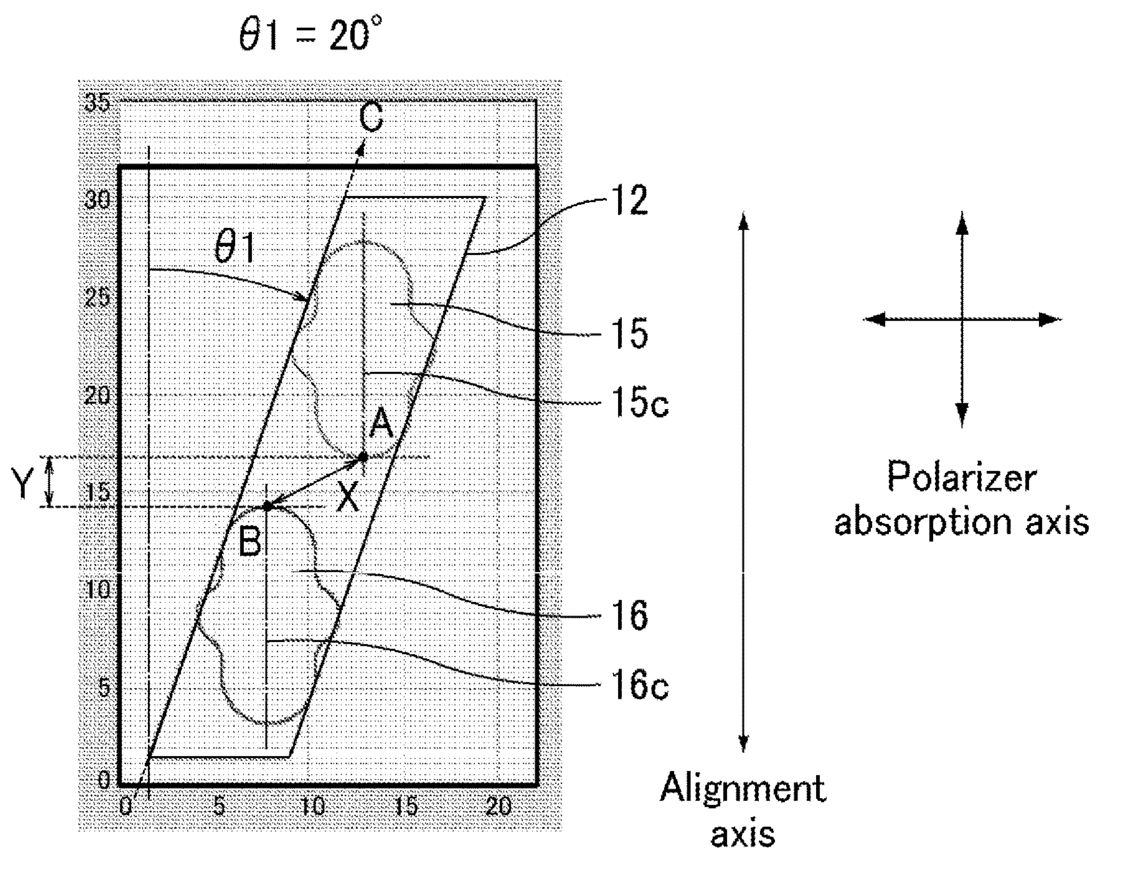

θ1 = 20°
35
30
25
20
15
10
5
0
0
5
10
15
20
C
θ1
A
X
Y
B
12
15
15c
16
16c
Alignment axis
Polarizer absorption axis

Fig. 29

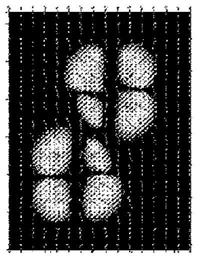
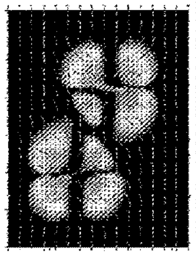
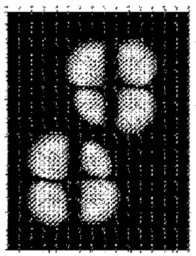
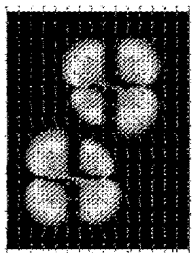
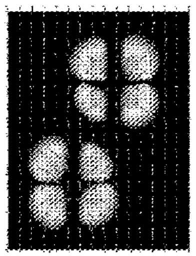
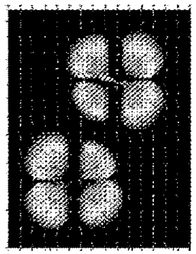
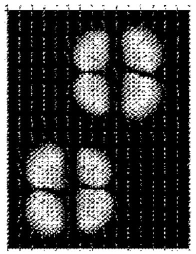
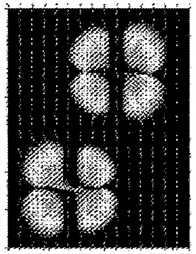
	Example 37		Example 38		Example 39		Example 40	
Y(μm)	0.5		1.5		2.5		4.5	
θ1(°)	20		20		20		20	
θ2(°)	0		0		0		0	
Applied voltage	5.0V	6.0V	5.0V	6.0V	5.0V	6.0V	5.0V	6.0V
Photograph								
Evaluation	Fair	Excellent	Fair	Good	Fair	Fair	Good	Good

Fig. 30

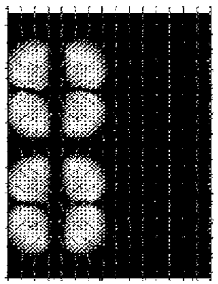
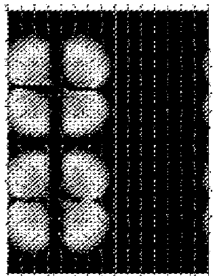
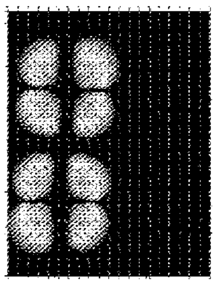
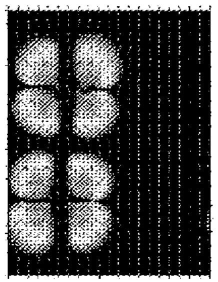
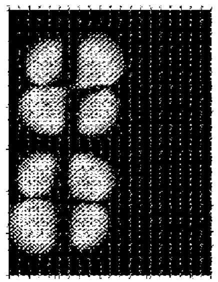
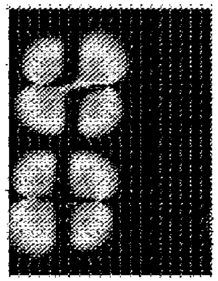
	Example 41		Example 42		Example 43	
Y(μm)	2.5		2.5		2.5	
θ1(°)	0		2		4	
θ2(°)	0		2		4	
Applied voltage	5.0V	6.0V	5.0V	6.0V	5.0V	6.0V
Photograph						
Evaluation	Good	Fair	Excellent	Excellent	Excellent	Excellent

Fig. 31

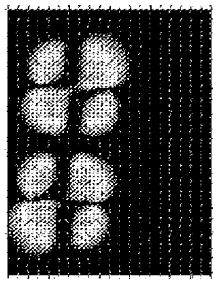
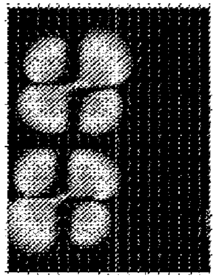
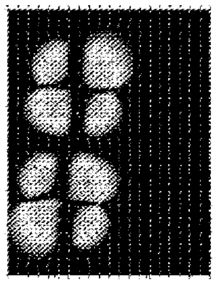
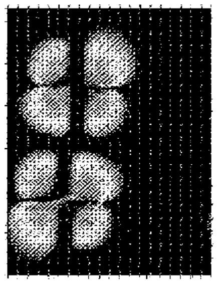
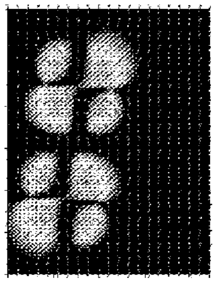
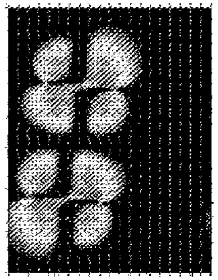
	Example 44		Example 45		Example 46	
Y(μm)	2.5		2.5		2.5	
θ1(°)	5		6		7	
θ2(°)	5		6		7	
Applied voltage	5.0V	6.0V	5.0V	6.0V	5.0V	6.0V
Photograph						
Evaluation	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent

Fig. 32

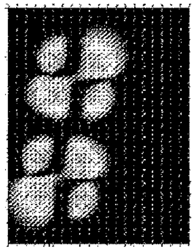
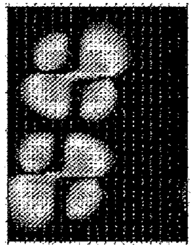
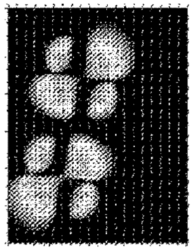
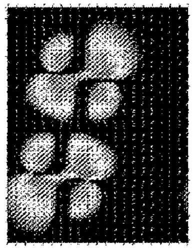
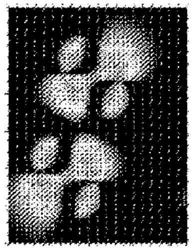
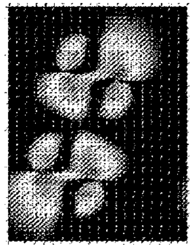
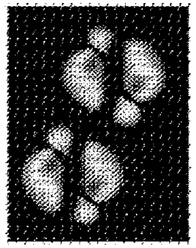
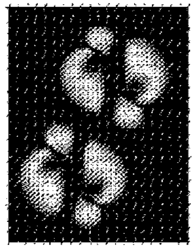
	Example 47		Example 48		Example 49		Example 50	
Y(μm)	2.5		2.5		2.5		2.5	
θ1(°)	8		10		14		20	
θ2(°)	8		10		14		20	
Applied voltage	5.0V	6.0V	5.0V	6.0V	5.0V	6.0V	5.0V	6.0V
Photograph								
Evaluation	Excellent	Excellent	Fair	Excellent	Fair	Fair	Fair	Fair

Fig. 33

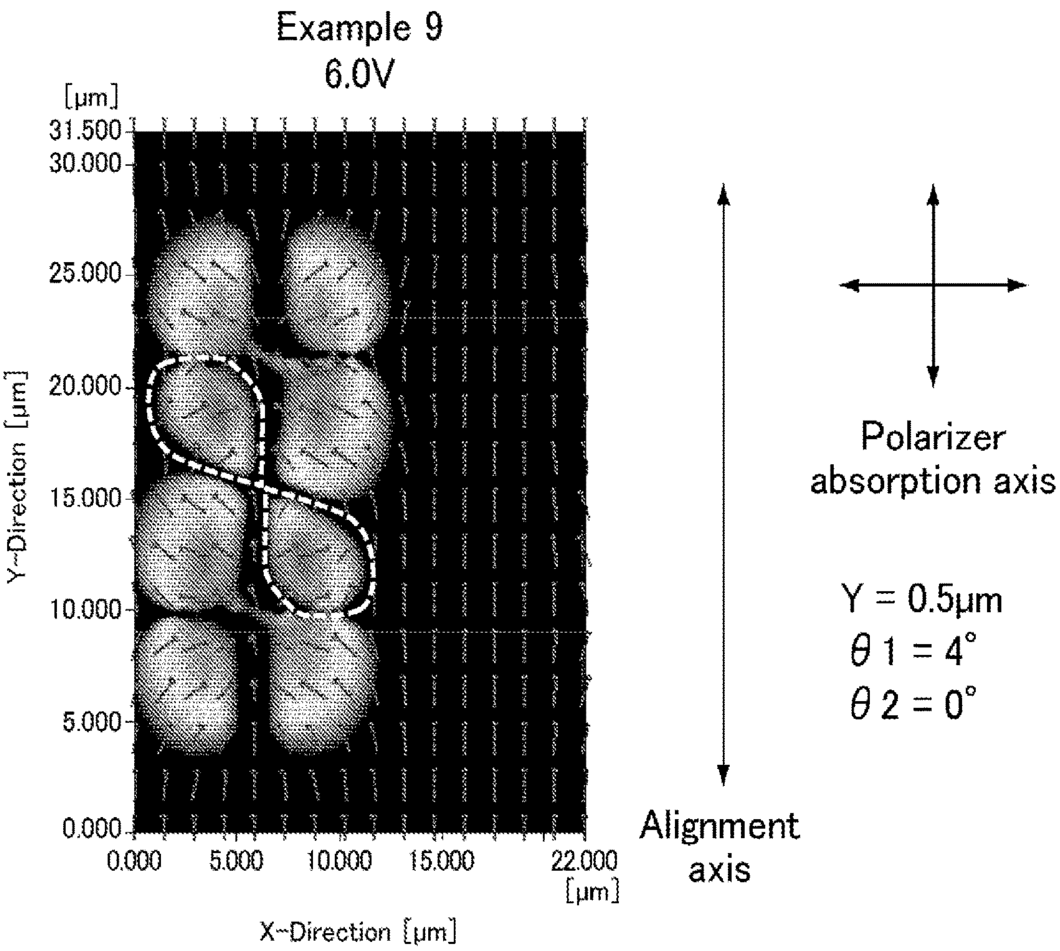

Example 9
6.0V
[μm]
31.500
30.000
25.000
20.000
15.000
10.000
5.000
0.000
Y-Direction [μm]
0.000
5.000
10.000
15.000
22.000
[μm]
X-Direction [μm]
Alignment axis
Polarizer absorption axis
Y = 0.5μm
θ1 = 4°
θ2 = 0°

Fig. 34

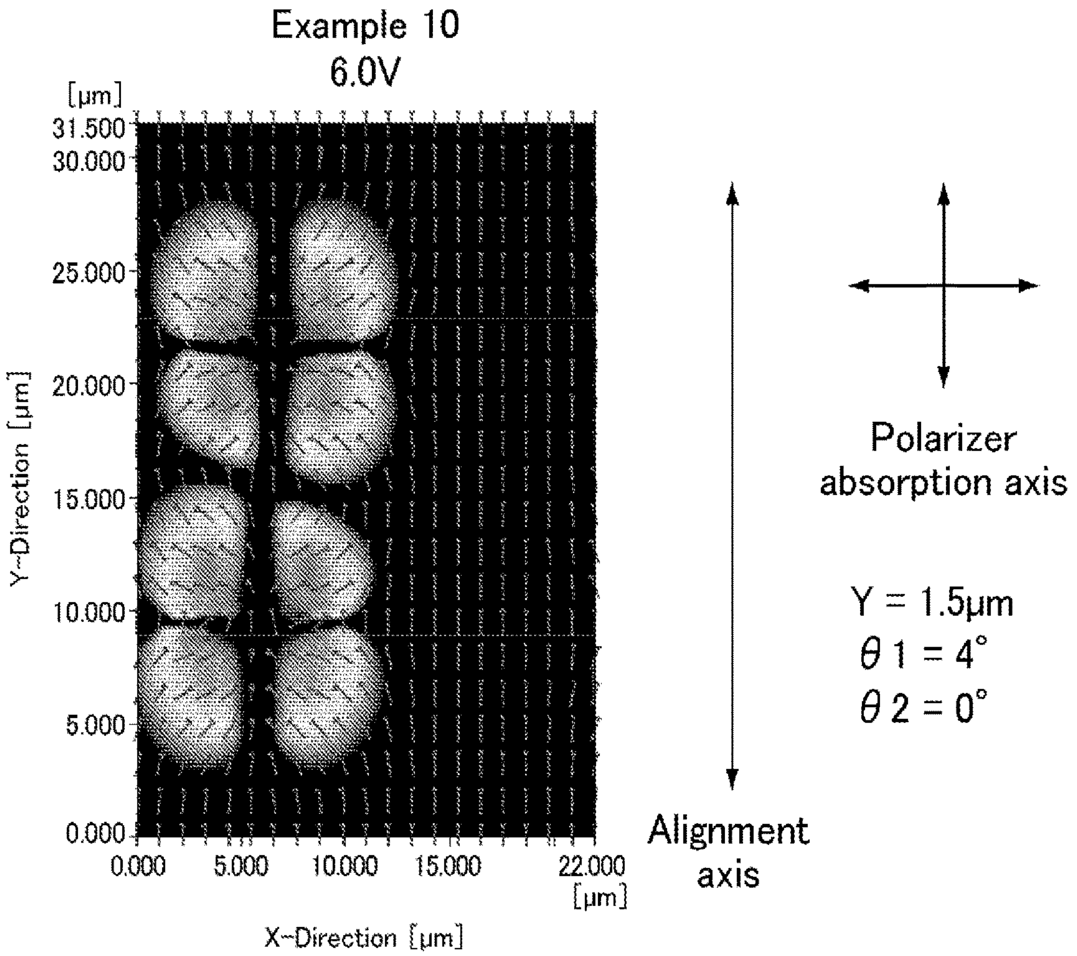

Example 10
6.0V
[μm]
31.500
30.000
25.000
20.000
15.000
10.000
5.000
0.000
Y-Direction [μm]
0.000
5.000
10.000
15.000
22.000
[μm]
X-Direction [μm]
Alignment
axis
Polarizer
absorption axis
Y = 1.5μm
θ1 = 4°
θ2 = 0°

Fig. 35

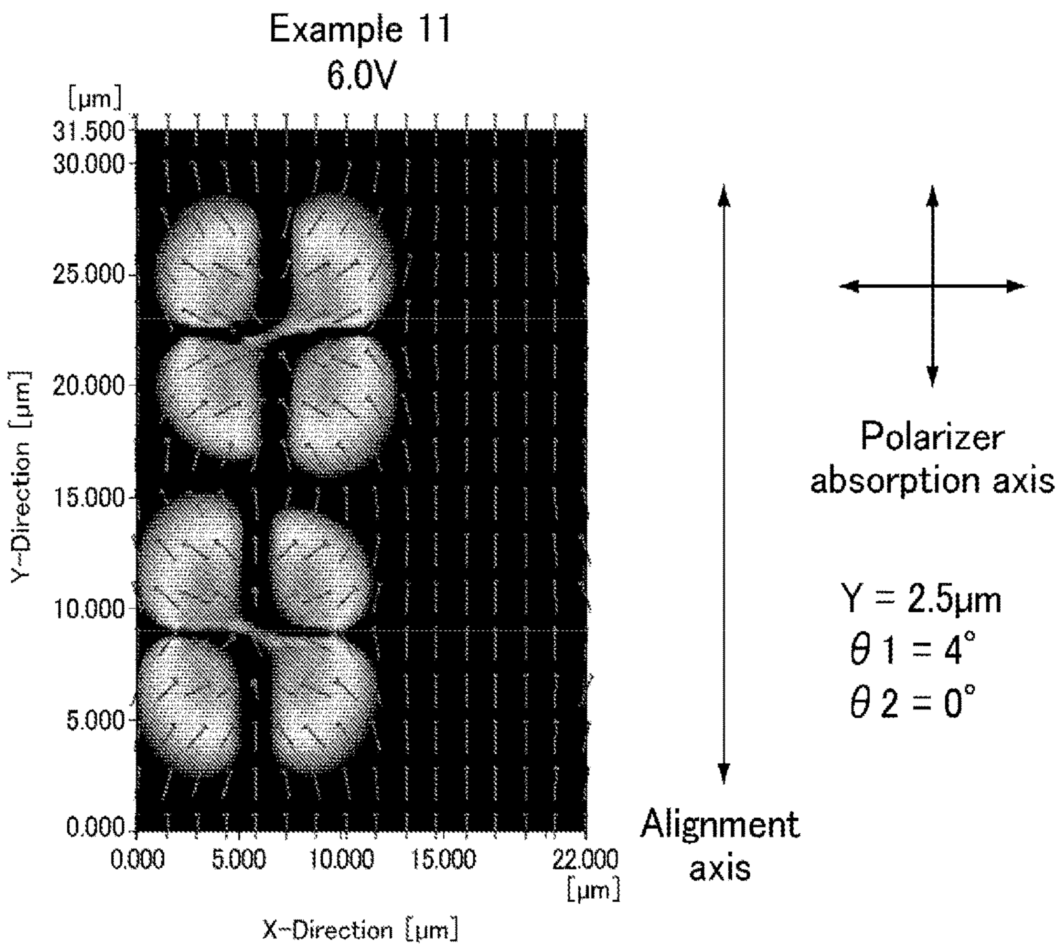

Example 11
6.0V
[μm]
31.500
30.000
25.000
20.000
15.000
10.000
5.000
0.000
Y-Direction [μm]
0.000
5.000
10.000
15.000
22.000
[μm]
X-Direction [μm]
Alignment axis
Polarizer absorption axis
Y = 2.5μm
θ 1 = 4°
θ 2 = 0°

Fig. 36

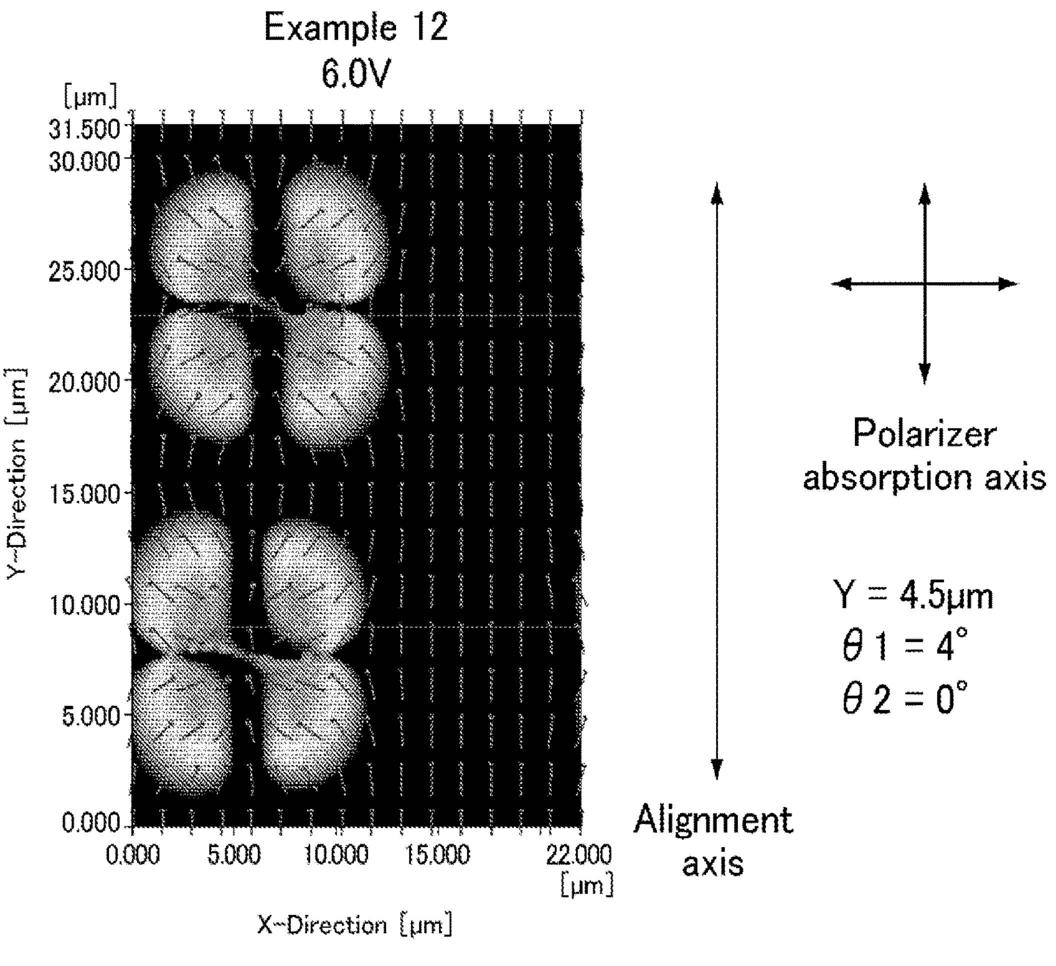

Example 12
6.0V
[μm]
31.500
30.000
25.000
20.000
15.000
10.000
5.000
0.000
Y-Direction [μm]
0.000
5.000
10.000
15.000
22.000
[μm]
X-Direction [μm]
Alignment axis
Polarizer absorption axis
Y = 4.5μm
θ1 = 4°
θ2 = 0°

Fig. 37

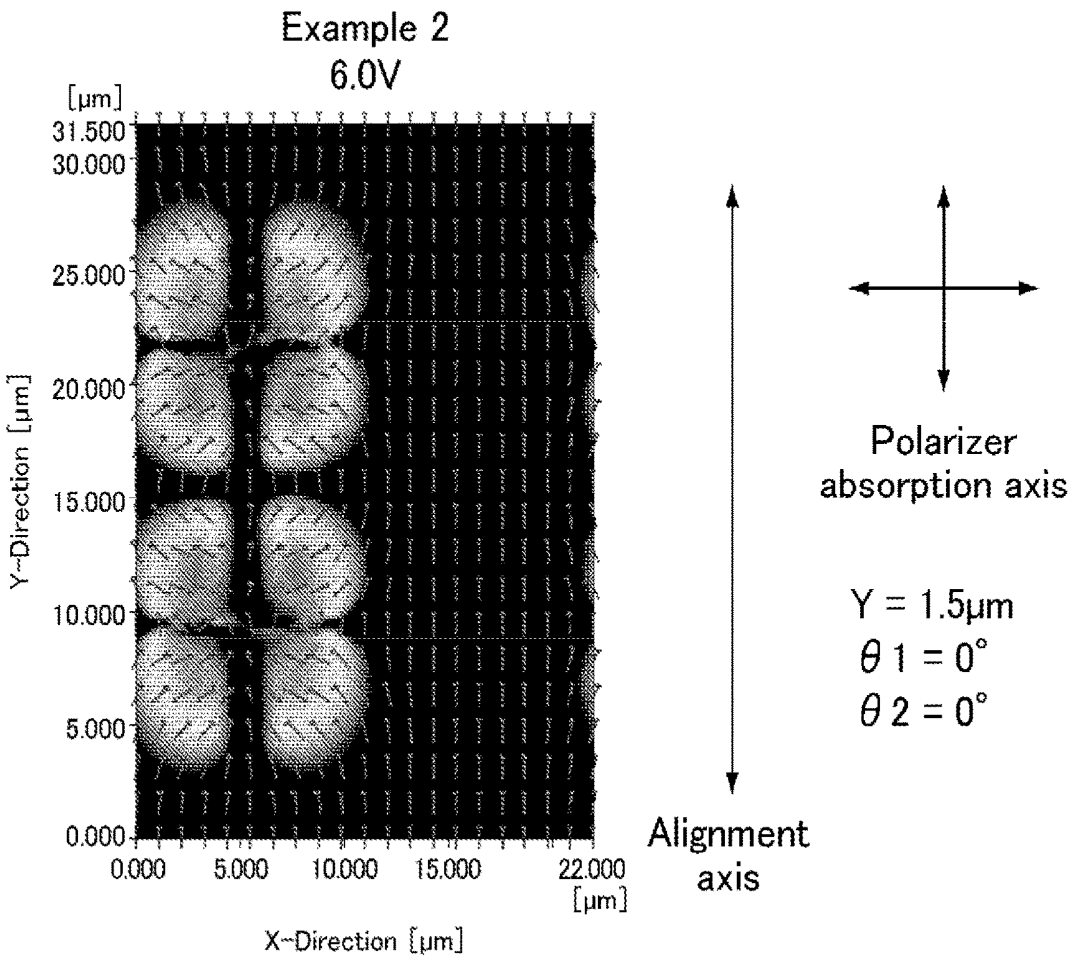

Example 2
6.0V
[μm]
31.500
30.000
25.000
20.000
15.000
10.000
5.000
0.000
Y-Direction [μm]
0.000
5.000
10.000
15.000
22.000
[μm]
X-Direction [μm]
Alignment axis
Polarizer absorption axis
Y = 1.5μm
θ1 = 0°
θ2 = 0°

Fig. 38

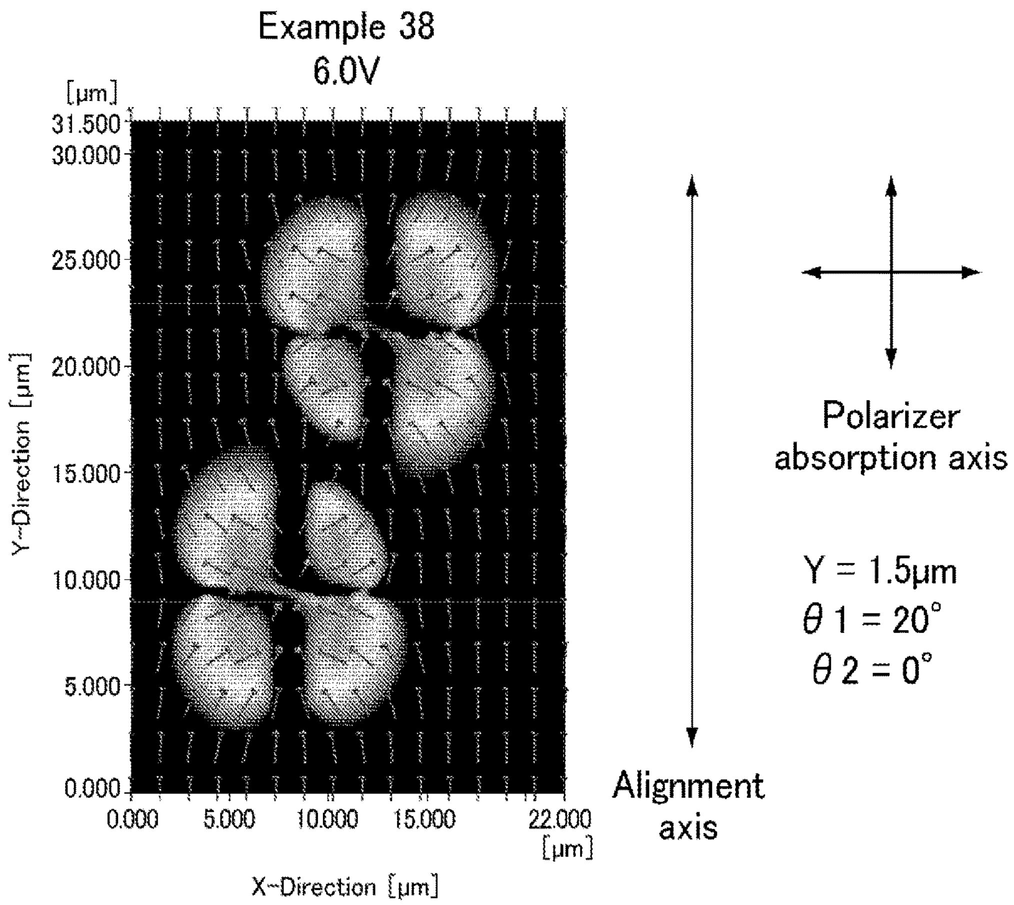

Example 38
6.0V
[μm]
31.500
30.000
25.000
20.000
15.000
10.000
5.000
0.000
Y-Direction [μm]
0.000
5.000
10.000
15.000
22.000
[μm]
X-Direction [μm]
Alignment axis
Polarizer absorption axis
Y = 1.5μm
θ 1 = 20°
θ 2 = 0°

Fig. 39

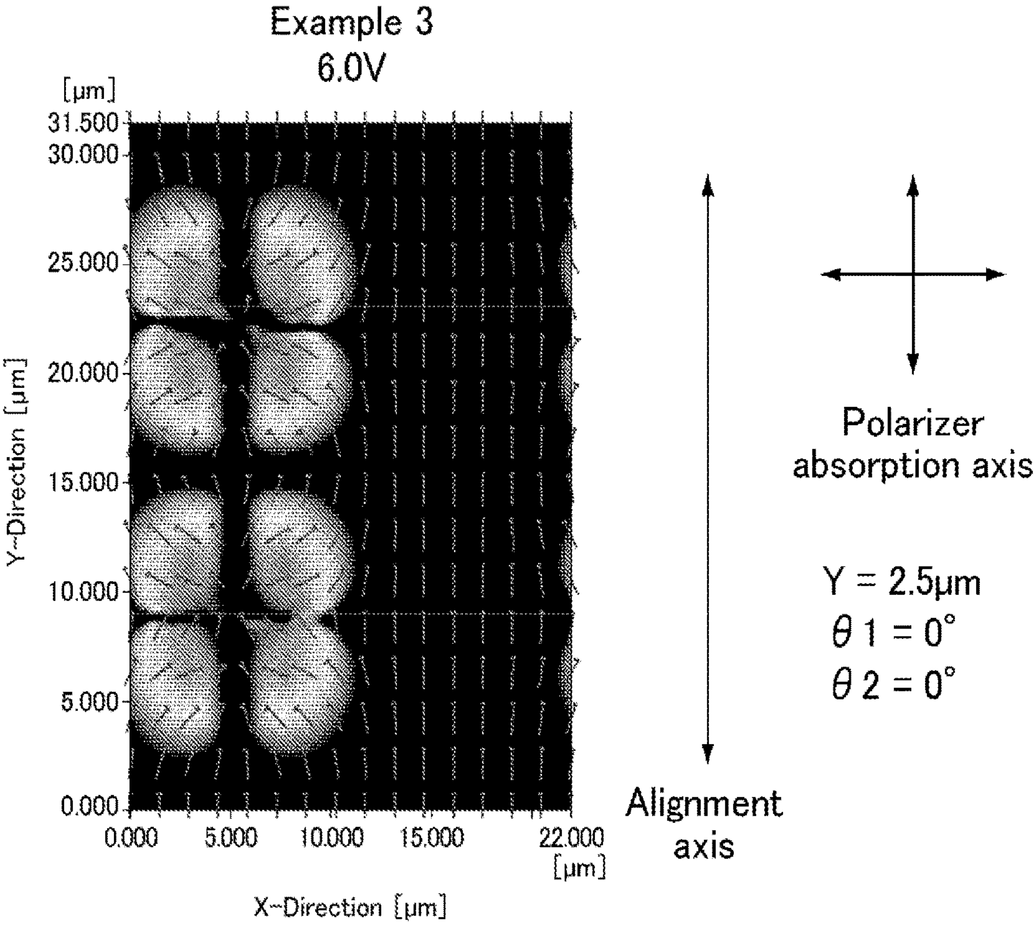

Example 3
6.0V
[μm]
31.500
30.000
25.000
20.000
15.000
10.000
5.000
0.000
Y-Direction [μm]
0.000
5.000
10.000
15.000
22.000
[μm]
X-Direction [μm]
Alignment axis
Polarizer absorption axis
Y = 2.5μm
θ1 = 0°
θ2 = 0°

Fig. 40

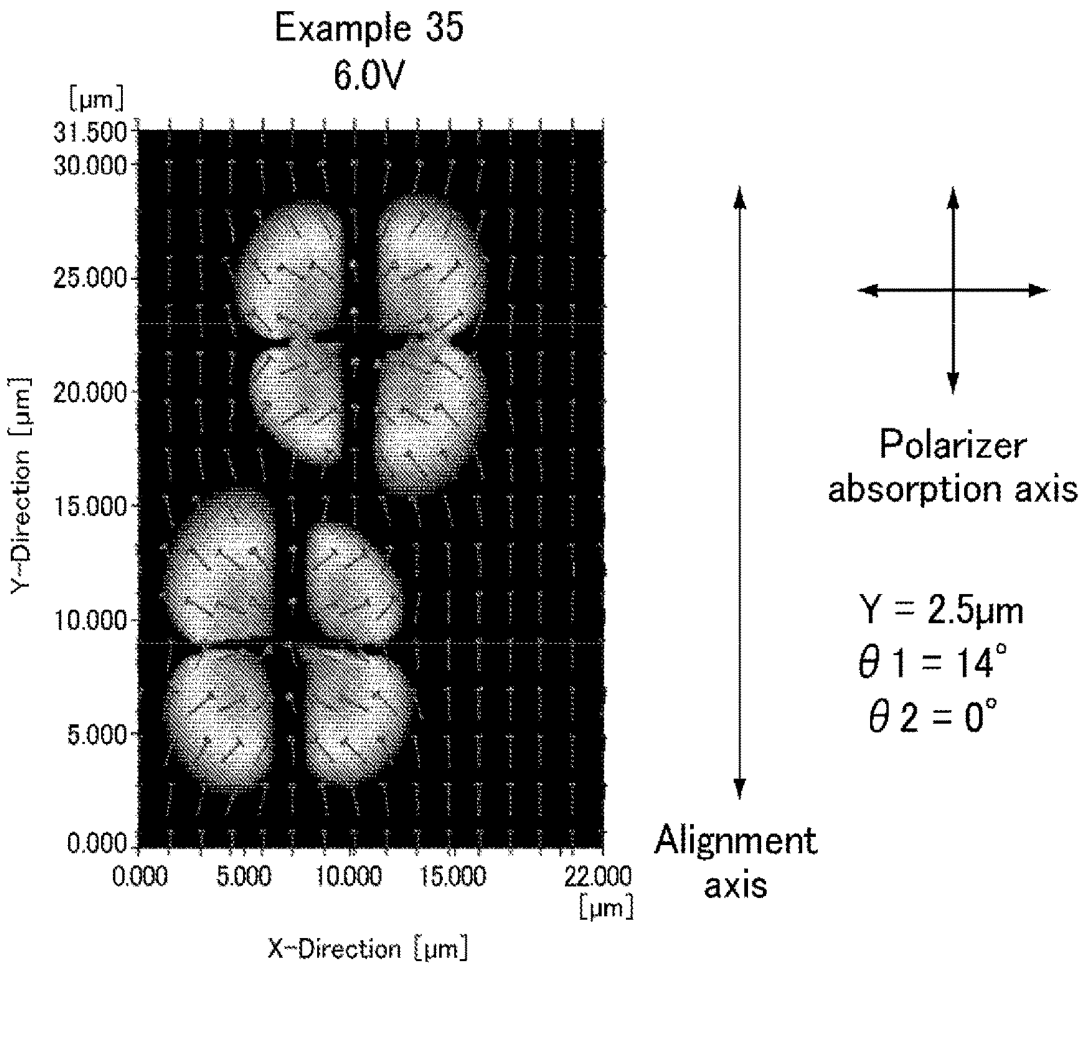

Example 35
6.0V
[μm]
31.500
30.000
25.000
20.000
15.000
10.000
5.000
0.000
Y-Direction [μm]
0.000
5.000
10.000
15.000
22.000
[μm]
X-Direction [μm]
Alignment axis
Polarizer absorption axis
Y = 2.5μm
θ 1 = 14°
θ 2 = 0°

Fig. 41

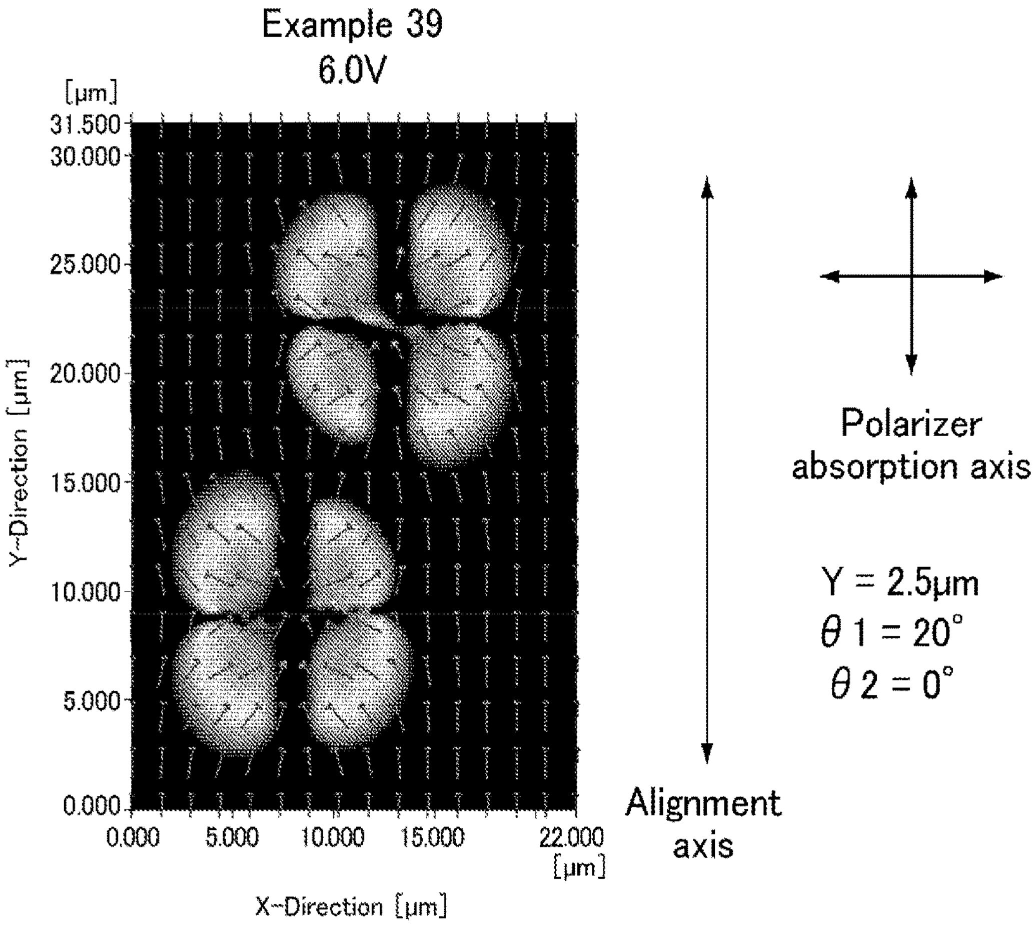

Example 39
6.0V
[μm]
31.500
30.000
25.000
20.000
15.000
10.000
5.000
0.000
Y-Direction [μm]
0.000
5.000
10.000
15.000
22.000
[μm]
X-Direction [μm]
Alignment
axis
Polarizer
absorption axis
Y = 2.5μm
θ 1 = 20°
θ 2 = 0°

Fig. 42

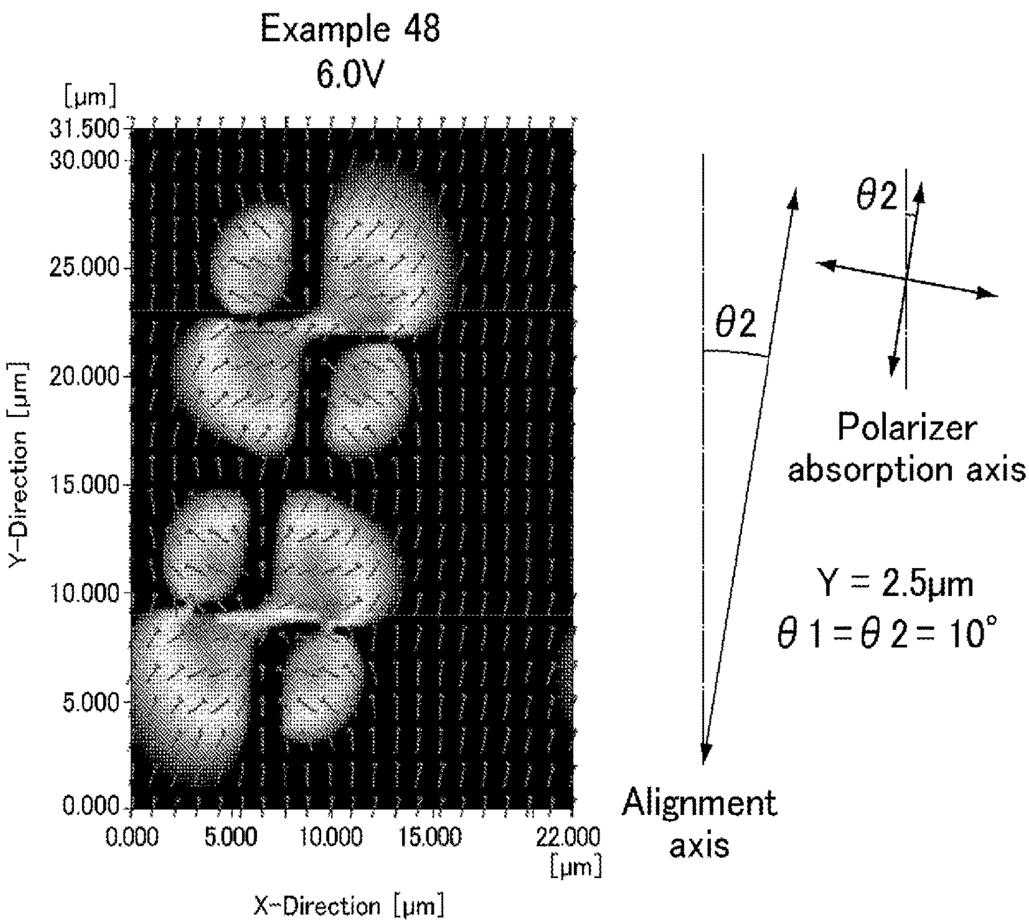

Example 48
6.0V
[μm]
31.500
30.000
25.000
20.000
15.000
10.000
5.000
0.000
Y-Direction [μm]
0.000
5.000
10.000
15.000
22.000
[μm]
X-Direction [μm]
θ2
θ2
Alignment
axis
Polarizer
absorption axis
Y = 2.5μm
θ1 = θ2 = 10°

Fig. 43

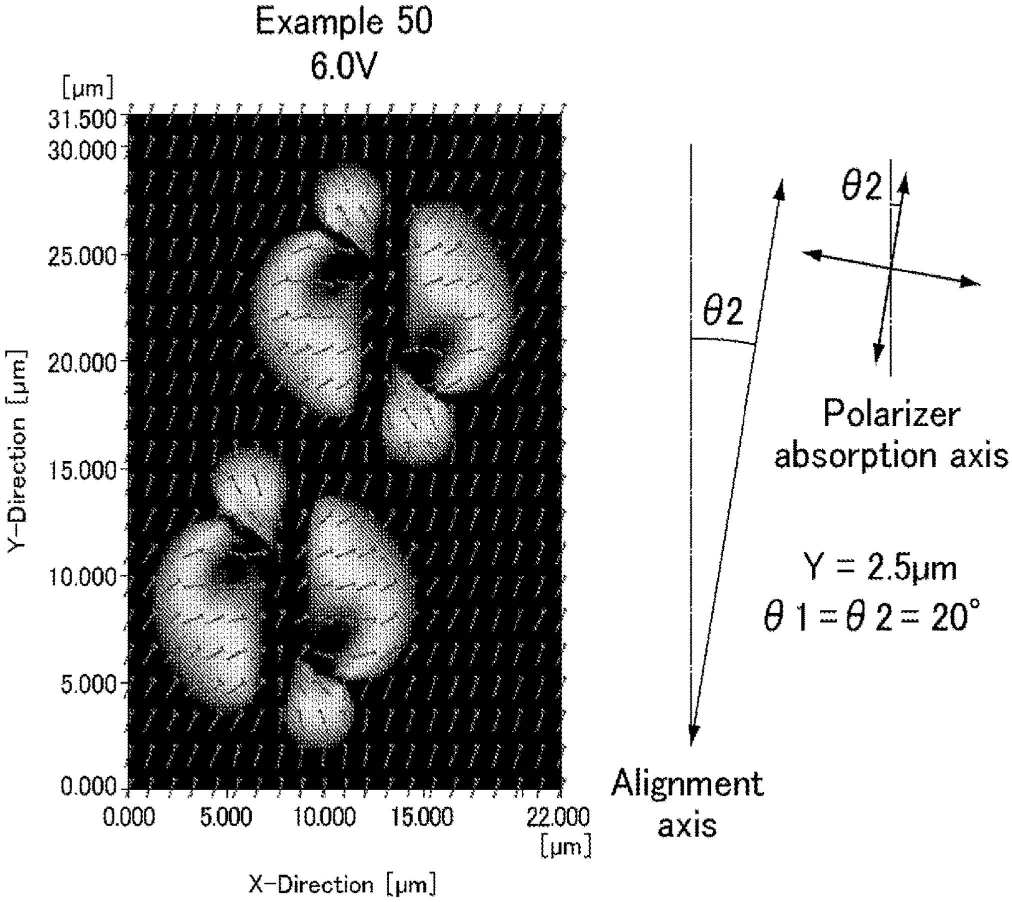

Example 50
6.0V
[μm]
31.500
30.000
25.000
20.000
15.000
10.000
5.000
0.000
Y-Direction [μm]
0.000
5.000
10.000
15.000
22.000
[μm]
X-Direction [μm]
θ2
θ2
Alignment
axis
Polarizer
absorption axis
Y = 2.5μm
θ 1 = θ 2 = 20°

Fig. 44

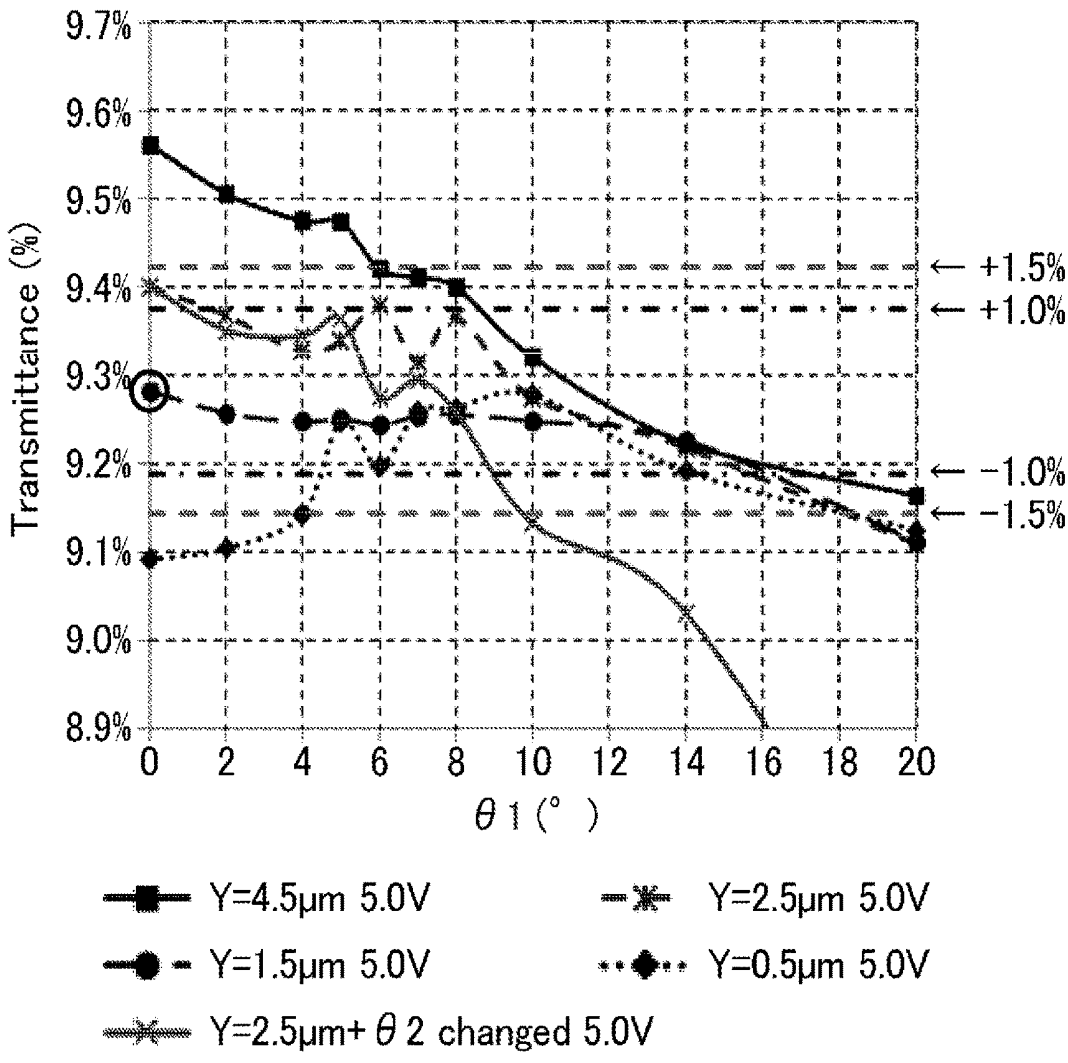

9.7%
9.6%
9.5%
9.4%
9.3%
9.2%
9.1%
9.0%
8.9%
Transmittance (%)
← +1.5%
← +1.0%
← −1.0%
← −1.5%
0
2
4
6
8
10
12
14
16
18
20
θ1 (°)
Y=4.5μm 5.0V
Y=2.5μm 5.0V
Y=1.5μm 5.0V
Y=0.5μm 5.0V
Y=2.5μm+ θ 2 changed 5.0V

Fig. 45

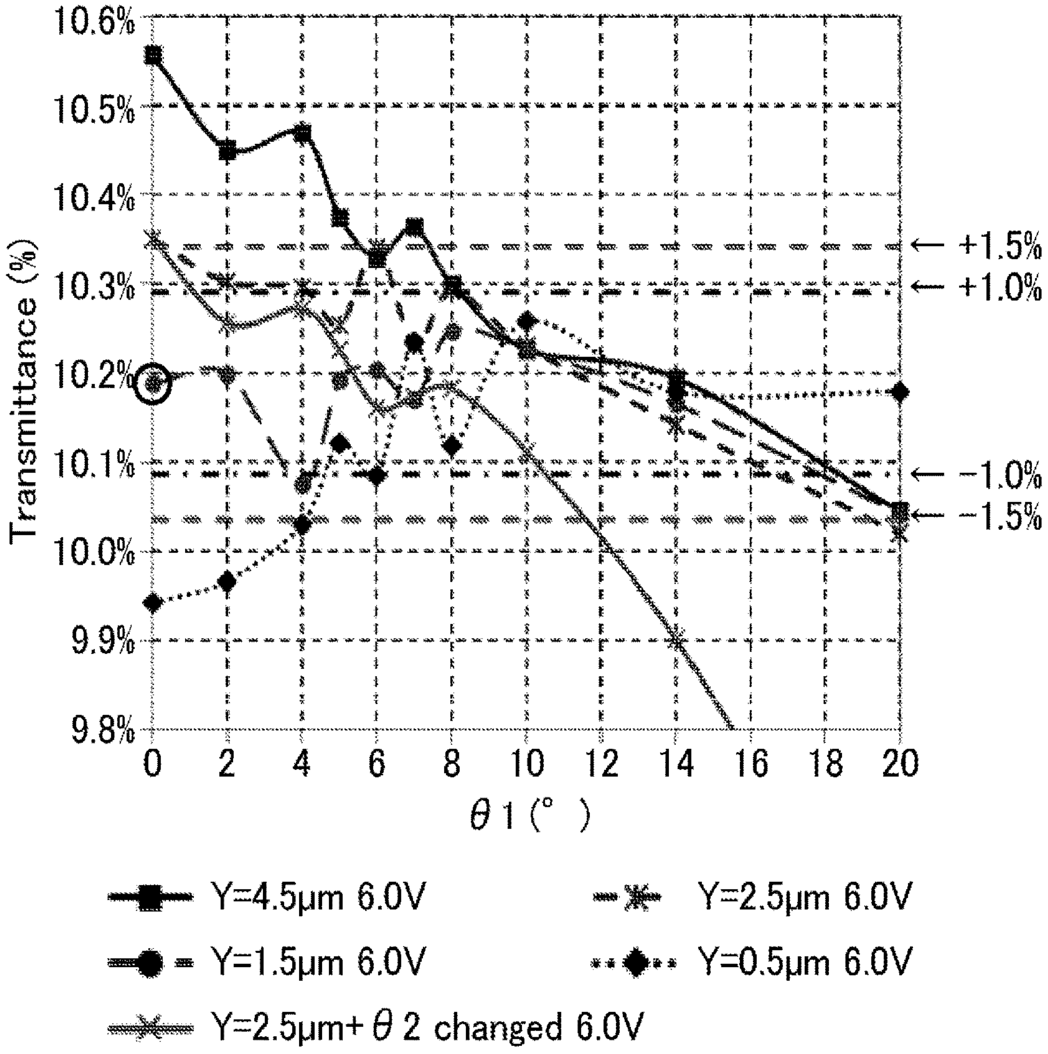

10.6%
10.5%
10.4%
10.3%
10.2%
10.1%
10.0%
9.9%
9.8%
Transmittance (%)
0 2 4 6 8 10 12 14 16 18 20
θ1 (°)
← +1.5%
← +1.0%
← −1.0%
← −1.5%
Y=4.5μm 6.0V
Y=2.5μm 6.0V
Y=1.5μm 6.0V
Y=0.5μm 6.0V
Y=2.5μm+θ2 changed 6.0V

Fig. 46

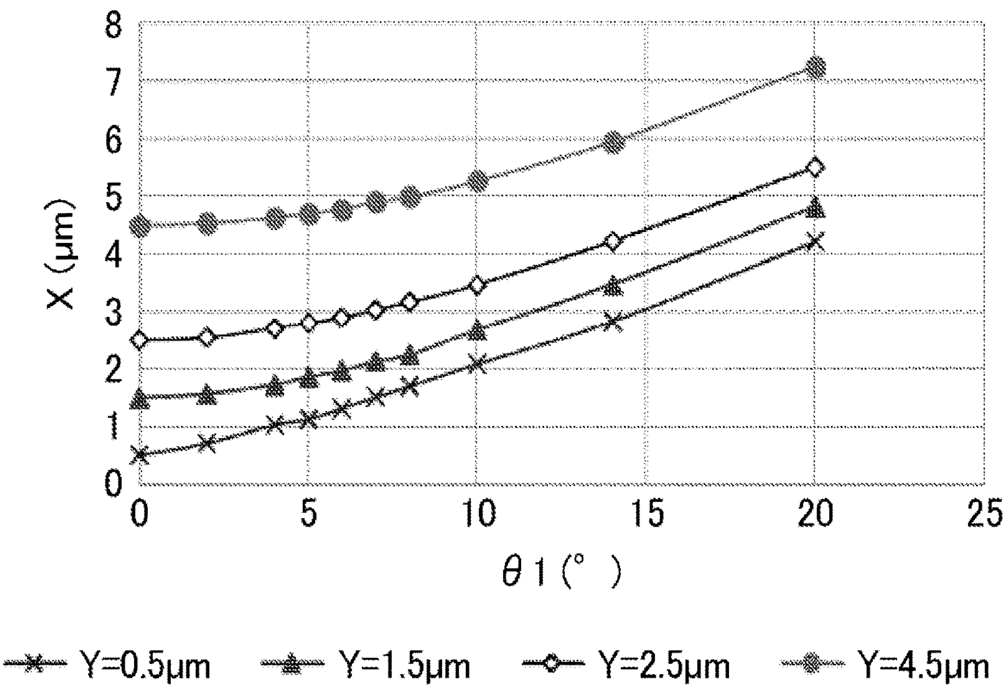


Fig. 47

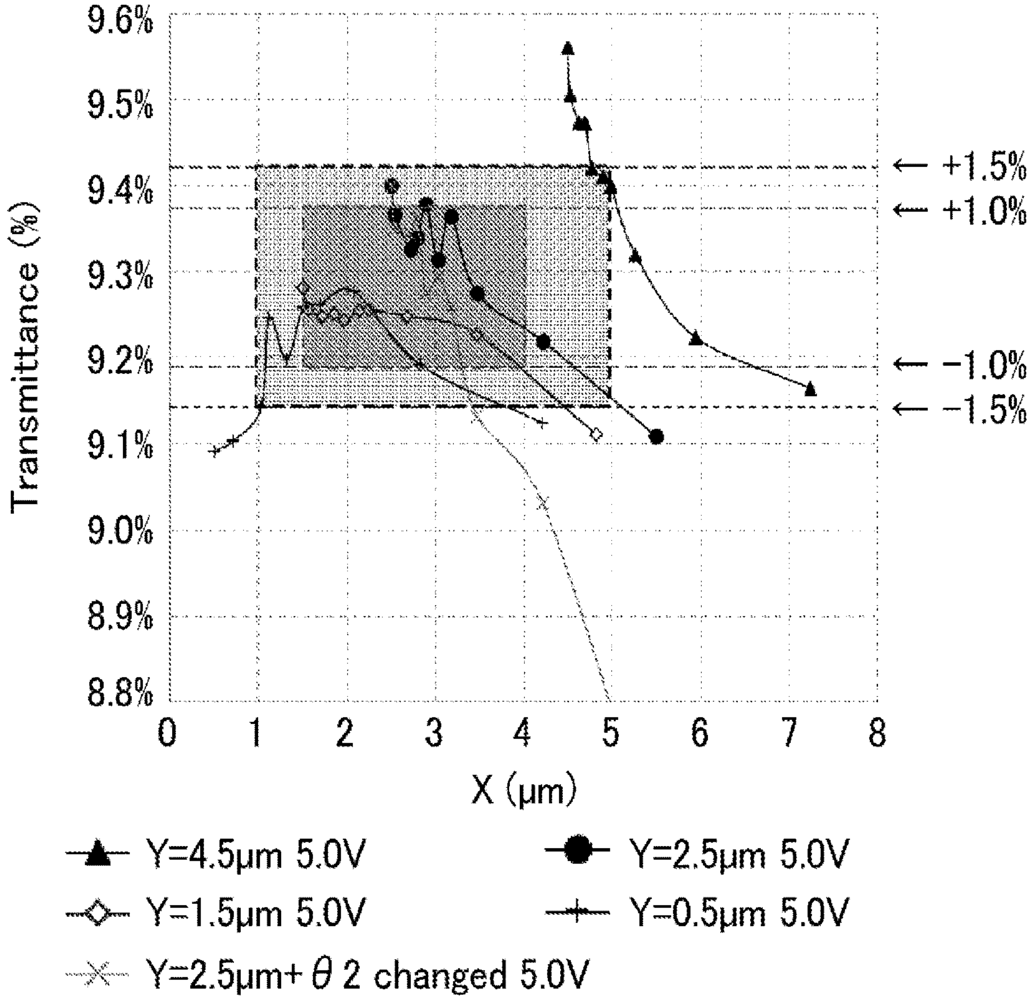
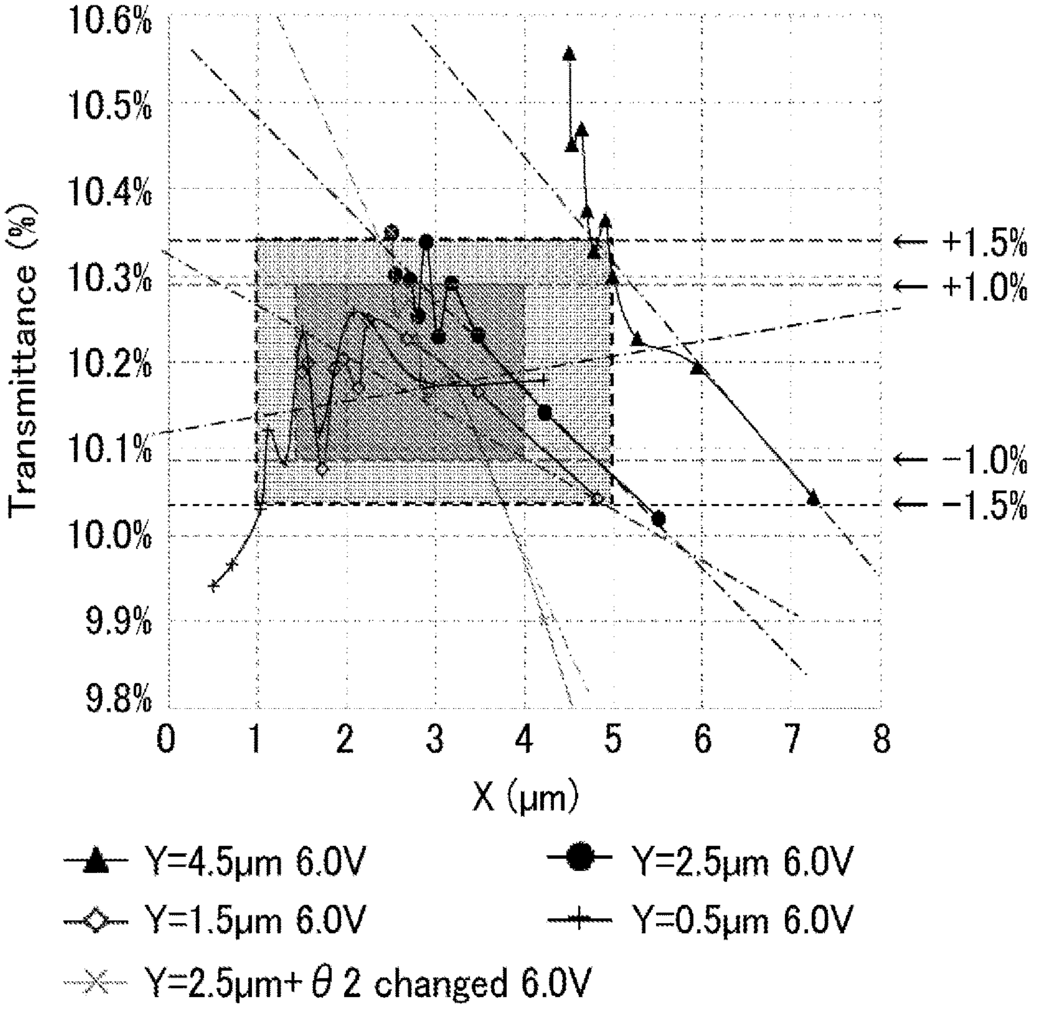

9.6%
9.5%
9.4%
9.3%
9.2%
9.1%
9.0%
8.9%
8.8%
Transmittance (%)
0
1
2
3
4
5
6
7
8
X (μm)
← +1.5%
← +1.0%
← −1.0%
← −1.5%
Y=4.5μm 5.0V
Y=2.5μm 5.0V
Y=1.5μm 5.0V
Y=0.5μm 5.0V
Y=2.5μm+θ 2 changed 5.0V

Fig. 48



10.6%
10.5%
10.4%
10.3%
10.2%
10.1%
10.0%
9.9%
9.8%
Transmittance (%)
0
1
2
3
4
5
6
7
8
X (μm)
← +1.5%
← +1.0%
← −1.0%
← −1.5%
Y=4.5μm 6.0V
Y=2.5μm 6.0V
Y=1.5μm 6.0V
Y=0.5μm 6.0V
Y=2.5μm+θ2 changed 6.0V

Fig. 49

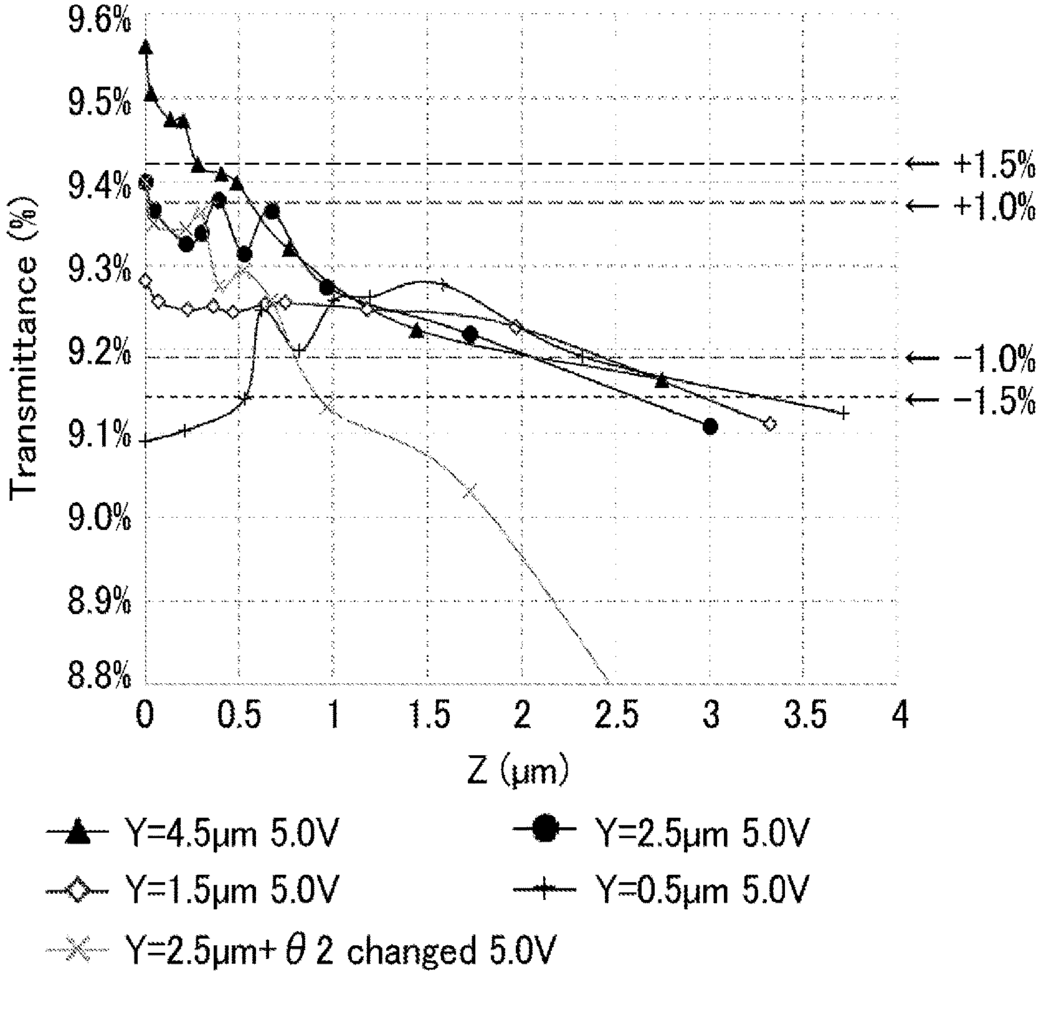
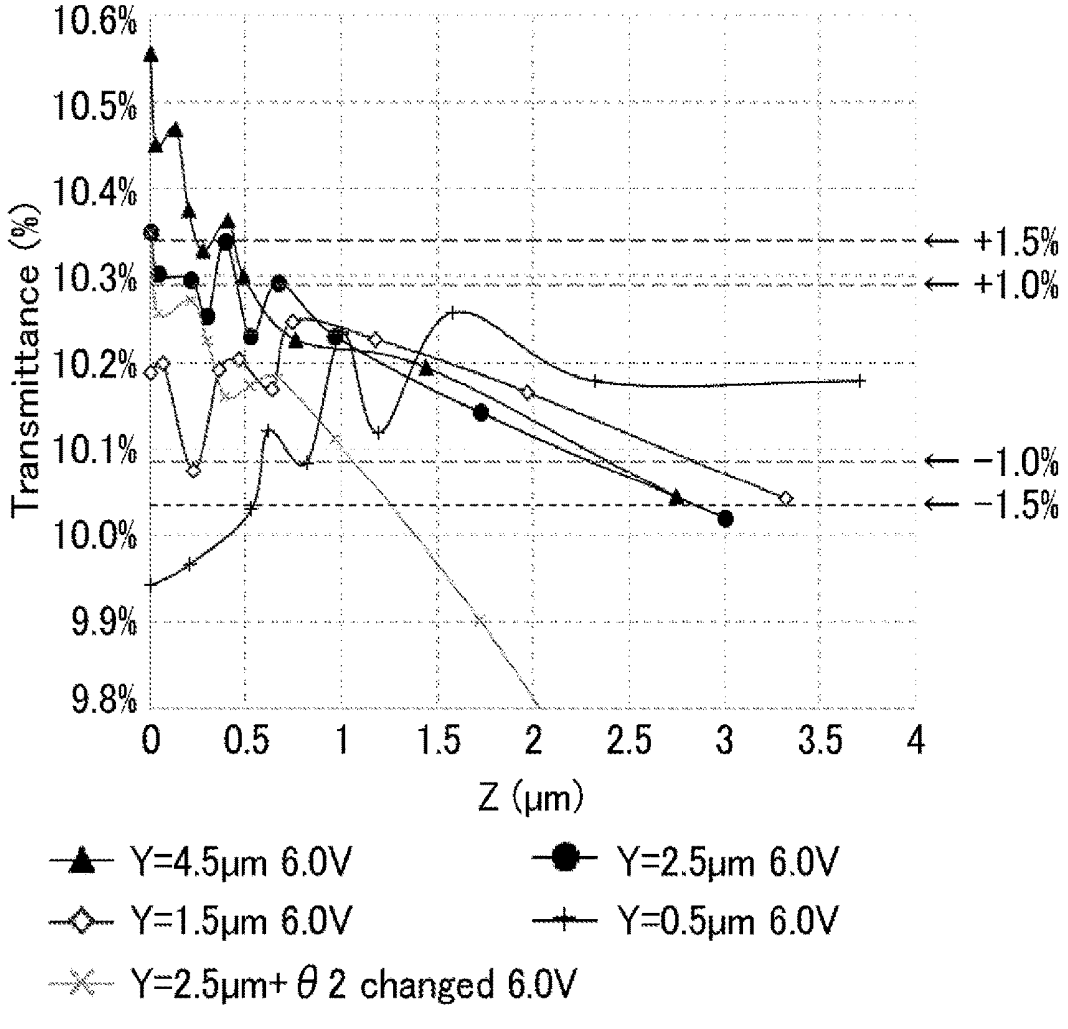

9.6%
9.5%
9.4%
9.3%
9.2%
9.1%
9.0%
8.9%
8.8%
Transmittance (%)
← +1.5%
← +1.0%
← −1.0%
← −1.5%
0
0.5
1
1.5
2
2.5
3
3.5
4
Z (μm)
Y=4.5μm 5.0V
Y=2.5μm 5.0V
Y=1.5μm 5.0V
Y=0.5μm 5.0V
Y=2.5μm+θ2 changed 5.0V

Fig. 50



10.6%
10.5%
10.4%
10.3%
10.2%
10.1%
10.0%
9.9%
9.8%
Transmittance (%)
0
0.5
1
1.5
2
2.5
3
3.5
4
Z (μm)
← +1.5%
← +1.0%
← −1.0%
← −1.5%
Y=4.5μm 6.0V
Y=2.5μm 6.0V
Y=1.5μm 6.0V
Y=0.5μm 6.0V
Y=2.5μm+ θ 2 changed 6.0V

LIQUID CRYSTAL DISPLAY DEVICE

TECHNICAL FIELD

[0001] The present invention relates to liquid crystal display devices. The present invention more specifically relates to a liquid crystal display device suitable as a horizontal alignment-mode liquid crystal display device provided with high-definition pixels.

BACKGROUND ART

[0002] Liquid crystal display devices are display devices that utilize a liquid crystal composition for display. A typical display mode thereof is applying voltage to a liquid crystal composition sealed between paired substrates to change the alignment state of liquid crystal molecules in the liquid crystal composition according to the applied voltage, thereby controlling the amount of light transmitted. These liquid crystal display devices, having characteristics such as thin profile, light weight, and low power consumption, have been used in a broad range of fields.

[0003] The display modes of liquid crystal display devices include horizontal alignment modes, which control the alignment of liquid crystal molecules by mainly rotating them in a plane parallel to the substrate surfaces. The horizontal alignment modes have received attention because these modes make it easy to achieve wide viewing angle characteristics. For example, the in-plane switching (IPS) mode and the fringe field switching (FFS) mode, both a type of horizontal alignment mode, are widely used in recent liquid crystal display devices for smartphones or tablet PCs.

[0004] There is continuing research and development of the horizontal alignment modes to achieve higher definition pixels, an improved transmittance, and an improved response speed to improve the display quality. With respect to techniques for improving the response speed, for example, Patent Literature 1 discloses a technique of providing a comb-teeth portion of a specific shape for a first electrode of a liquid crystal display device utilizing a fringe electric field.

CITATION LIST

Patent Literature

[0005] Patent Literature 1: JP 2015-114493 A

SUMMARY OF INVENTION

Technical Problem

[0006] The horizontal alignment modes offer the advantage of wide viewing angles, but have the problem of slow response as compared to vertical alignment modes such as the multi-domain vertical alignment (MVA) mode. Patent Literature 1 discloses that the response speed can be improved by providing a comb-teeth portion of a specific shape for a first electrode. Nevertheless, the shape of the electrode is greatly limited for ultra-high-definition pixels of 800 ppi or more, for example, and thus a complicated electrode shape as disclosed in Patent Literature 1 is difficult to form.

[0007] As mentioned above, there is a demand for a technique capable of improving the response speed in horizontal alignment-mode liquid crystal display devices with high-definition pixels.

[0008] The present invention has been made in view of the above current state of the art, and aims to provide a horizontal alignment-mode liquid crystal display device that achieves both higher definition and an improved response speed.

Solution to Problem

[0009] The present inventors performed various studies on horizontal alignment-mode liquid crystal display devices enabling high definition and rapid response, and focused on the shape of an opening of an electrode used for formation of a fringe electric field. The inventors then found that the alignment of liquid crystal molecules can be controlled without a complicated opening shape by providing a first opening and a second opening which are independent of each other and point-symmetrical to each other, the first opening and the second opening each having a shape including: curved portions that expand an opening periphery outward at the respective ends in the longitudinal direction; and paired protruding portions that allow the opening periphery to protrude partially in the lateral direction in the middle of the longitudinal direction. This configuration enables higher definition and an improved response speed, and thus the present inventors have arrived at the solution of the above problems, completing the present invention.

[0010] Specifically, one aspect of the present invention may be a liquid crystal display device including, in the given order: a first substrate; a liquid crystal layer containing liquid crystal molecules; and a second substrate, the first substrate including a first electrode, a second electrode closer to the liquid crystal layer than the first electrode is, and an insulating film between the first electrode and the second electrode, the second electrode being provided with openings including a first opening and a second opening adjacent to each other, the first opening and the second opening being independent of each other and point-symmetrical to each other, the first opening and the second opening each having a shape including: curved portions that expand an opening periphery outward at the respective ends in the longitudinal direction; and paired protruding portions that allow the opening periphery to protrude partially in the lateral direction in the middle of the longitudinal direction, the liquid crystal molecules being aligned parallel to the first substrate in a no-voltage-applied state where no voltage is applied between the first electrode and the second electrode.

Advantageous Effects of Invention

[0011] The present invention enables higher definition and an improved response speed in a horizontal alignment-mode liquid crystal display device.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] FIG. **1** is a schematic cross-sectional view of a liquid crystal display device of Embodiment 1 in the off state.

[0013] FIG. **2** is a schematic cross-sectional view of the liquid crystal display device of Embodiment 1 in the on state.

[0014] FIG. **3** is a schematic plan view of a counter electrode in the liquid crystal display device of Embodiment 1.

[0015] FIG. **4** is a schematic plan view of a pixel electrode in the liquid crystal display device of Embodiment 1.

[0016] FIG. **5** is a schematic plan view of an exemplary display unit in the liquid crystal display device of Embodiment 1.

[0017] FIG. **6** is a schematic plan view of another exemplary display unit in the liquid crystal display device of Embodiment 1.

[0018] FIG. **7** is a schematic plan view of the liquid crystal display device of Embodiment 1.

[0019] FIGS. **8** schematically illustrate control of the alignment of liquid crystal molecules in the liquid crystal display device of Embodiment 1; FIG. **8(1)** shows the off state and FIG. **8(2)** shows the on state.

[0020] FIG. **9** is an enlarged plan view showing the simulation result of the distribution of the alignments of liquid crystal molecules in the region surrounded by the dotted line in FIG. **8(2)**.

[0021] FIG. **10** is a plan view showing the simulation results of Example 1.

[0022] FIG. **11** is a table showing the simulation results of Examples 1 to 4.

[0023] FIG. **12** is a schematic plan view of a display unit in a liquid crystal display device of Example 5.

[0024] FIG. **13** is a table showing the simulation results of Examples 5 to 8.

[0025] FIG. **14** is a schematic plan view of a display unit in a liquid crystal display device of Example 9.

[0026] FIG. **15** is a table showing the simulation results of Examples 9 to 12.

[0027] FIG. **16** is a schematic plan view of a display unit in a liquid crystal display device of Example 13.

[0028] FIG. **17** is a table showing the simulation results of Examples 13 to 16.

[0029] FIG. **18** is a schematic plan view of a display unit in a liquid crystal display device of Example 17.

[0030] FIG. **19** is a table showing the simulation results of Examples 17 to 20.

[0031] FIG. **20** is a schematic plan view of a display unit in a liquid crystal display device of Example 21.

[0032] FIG. **21** is a table showing the simulation results of Examples 21 to 24.

[0033] FIG. **22** is a schematic plan view of a display unit in a liquid crystal display device of Example 25.

[0034] FIG. **23** is a table showing the simulation results of Examples 25 to 28.

[0035] FIG. **24** is a schematic plan view of a display unit in a liquid crystal display device of Example 29.

[0036] FIG. **25** is a table showing the simulation results of Examples 29 to 32.

[0037] FIG. **26** is a schematic plan view of a display unit in a liquid crystal display device of Example 33.

[0038] FIG. **27** is a table showing the simulation results of Examples 33 to 36.

[0039] FIG. **28** is a schematic plan view of a display unit in a liquid crystal display device of Example 37.

[0040] FIG. **29** is a table showing the simulation results of Examples 37 to 40.

[0041] FIG. **30** is a table showing the simulation results of Examples 41 to 43.

[0042] FIG. **31** is a table showing the simulation results of Examples 44 to 46.

[0043] FIG. **32** is a table showing the simulation results of Examples 47 to 50.

[0044] FIG. **33** is a plan view showing the simulation results of Example 9.

[0045] FIG. **34** is a plan view showing the simulation results of Example 10.

[0046] FIG. **35** is a plan view showing the simulation results of Example 11.

[0047] FIG. **36** is a plan view showing the simulation results of Example 12.

[0048] FIG. **37** is a plan view showing the simulation results of Example 2.

[0049] FIG. **38** is a plan view showing the simulation results of Example 38.

[0050] FIG. **39** is a plan view showing the simulation results of Example 3.

[0051] FIG. **40** is a plan view showing the simulation results of Example 35.

[0052] FIG. **41** is a plan view showing the simulation results of Example 39.

[0053] FIG. **42** is a plan view showing the simulation results of Example 48.

[0054] FIG. **43** is a plan view showing the simulation results of Example 50.

[0055] FIG. **44** is a graph showing the relationship between the angle $\theta 1$ and the transmittance at an applied voltage of 5.0 V.

[0056] FIG. **45** is a graph showing the relationship between the angle $\theta 1$ and the transmittance at an applied voltage of 6.0 V.

[0057] FIG. **46** is a graph showing the relationship between the distance (X) between the vertices of the openings and the angle $\theta 1$.

[0058] FIG. **47** is a graph showing the relationship between the distance (X) between the vertices of the openings and the transmittance at an applied voltage of 5.0 V.

[0059] FIG. **48** is a graph showing the relationship between the distance (X) between the vertices of the openings and the transmittance at an applied voltage of 6.0 V.

[0060] FIG. **49** is a graph showing the relationship between the value Z and the transmittance at an applied voltage of 5.0 V.

[0061] FIG. **50** is a graph showing the relationship between the value Z and the transmittance at an applied voltage of 6.0 V.

DESCRIPTION OF EMBODIMENTS

[0062] Hereinafter, an embodiment of the present invention will be described. The following embodiment, however, is not intended to limit the scope of the present invention. The present invention may appropriately be modified within the scope of the configuration of the present invention. The same components or components having the same or similar function are commonly provided with the same reference sign in the drawings, and description of such components is not repeated. The configurations described in the embodiment may appropriately be combined or modified within the spirit of the present invention.

Embodiment 1

[0063] With reference to FIGS. **1** to **8**, a liquid crystal display device of Embodiment 1 will be described below. FIG. **1** is a schematic cross-sectional view of a liquid crystal display device of Embodiment 1 in the off state. FIG. **2** is a schematic cross-sectional view of the liquid crystal display device of Embodiment 1 in the on state. FIG. **3** is a schematic plan view of a counter electrode in the liquid crystal display device of Embodiment 1. FIG. **4** is a schematic plan view of a pixel electrode in the liquid crystal display device of Embodiment 1. FIG. **5** is a schematic plan view of an exemplary display unit in the liquid crystal display device of Embodiment 1. FIG. **6** is a schematic plan view of another exemplary display unit in the liquid crystal display device of Embodiment 1. FIG. **7** is a schematic plan view of the liquid crystal display device of Embodiment 1. FIGS. **8** schematically illustrate control of the alignment of liquid crystal molecules in the liquid crystal display device of Embodiment 1; FIG. **8**(**1**) shows the off state and FIG. **8**(**2**) shows the on state. The cross-sections shown in FIG. **1** and FIG. **2** are taken along the a-b line in FIG. **8**.

[0064] As shown in FIG. **1**, a liquid crystal display device **100** of Embodiment 1 includes, in the given order, a first substrate **10**, a liquid crystal layer **20** containing liquid crystal molecules **21**, and a second substrate **30**. The first substrate **10** is a TFT array substrate and has a stacked structure including, in the order toward the liquid crystal layer **20**, a first polarizer (not shown), an insulating substrate (e.g., glass substrate) **11**, a pixel electrode (first electrode) **12**, an insulating layer (insulating film) **13**, and a counter electrode (second electrode) **14**. The second substrate **30** is a color filter substrate and has a stacked structure including, in the order toward the liquid crystal layer **20**, a second polarizer (not shown), an insulating substrate (e.g., glass substrate) **31**, a color filter **32**, and an overcoat layer **33**. The first polarizer and the second polarizer are both absorptive polarizers and disposed in the crossed Nicols with their absorption axes perpendicular to each other.

[0065] Although not shown in FIG. **1**, a horizontal alignment film is typically disposed on the surface closer to the liquid crystal layer **20** of the first substrate **10** and/or the second substrate **30**. The horizontal alignment film acts to align liquid crystal molecules near the film parallel to the film surface. In addition, the horizontal alignment film adjusts the orientations of the major axes (hereinafter also referred to as "alignment azimuths") of the liquid crystal molecules **21** aligned parallel to the first substrate **10** to a specific in-plane azimuth. The horizontal alignment film has preferably been subjected to alignment treatment such as photo-alignment treatment or rubbing treatment. The horizontal alignment film may be made of an inorganic material or an organic material.

[0066] The alignment mode of the liquid crystal display device **100** is the fringe field switching (FFS) mode.

[0067] In the no-voltage-applied state (the off state) where no voltage is applied between the pixel electrode **12** and the counter electrode **14**, the alignment of the liquid crystal molecules **21** are controlled to be parallel to the first substrate **10**. The "parallel" herein includes not only being completely parallel, but also a range that can be equated with being parallel (substantially parallel) in the field of the art. The pre-tilt angle (inclination angle in the off state) of the liquid crystal molecules **21** is preferably smaller than 3°, more preferably smaller than 1° relative to the surface of the first substrate **10**.

[0068] In the liquid crystal layer **20** in the voltage-applied state (the on state), the alignment of the liquid crystal molecules **21** is controlled by the stacked structure of the first substrate **10** including the pixel electrode **12**, the insulating layer **13**, and the counter electrode **14**. The pixel electrode **12** is an electrode provided for each display unit. The counter electrode **14** is an electrode common to multiple display units. The "display unit" means a region corresponding to one pixel electrode **12**. The display unit may be one called "pixel" in the technical field of liquid crystal display devices, or may be one called "sub-pixel" or "dot" in cases where one pixel is divided for driving.

[0069] The positions of the counter electrode **14** and the pixel electrode **12** may be switched. Specifically, although the counter electrode **14** is adjacent to the liquid crystal layer **20** via a horizontal alignment film (not shown) in the stacked structure shown in FIG. **1**, the pixel electrode **12** may be adjacent to the liquid crystal layer **20** via the horizontal alignment film (not shown). In such a case, a first opening **15** and a second opening **16** described later are formed not in the counter electrode **14** but in the pixel electrode **12**.

[0070] As shown in FIG. **3**, the counter electrode **14** is provided with openings including the first opening **15** and the second opening **16** adjacent to each other. The first opening **15** and the second opening **16** are used for formation of a fringe electric field (oblique electric field). The first opening **15** and the second opening **16** are preferably provided per display unit, and preferably provided for all the display units.

[0071] The first opening **15** and the second opening **16** each have a shape including: curved portions that expand an opening periphery outward at the respective ends in the longitudinal direction; and paired protruding portions **15*a*** and **16*a***, respectively, that allow the opening periphery to protrude partially in the lateral direction in the middle of the longitudinal direction. As shown in FIG. **3**, taking the paired protruding portions **15*a*** as an example, without consideration of the protruding portions, the opening periphery protrudes to the counter electrode **14** sides from reference lines **15*b*** (dotted lines in FIG. **3**) that are the straight lines linking the peripheral portions in the longitudinal direction of the first opening **15**. This peripheral shape includes no complicated shape, and thus can be applied to ultra-high-definition pixels of 800 ppi or more, for example. Further, the first opening **15** and the second opening **16** each have a shape including curved portions that expand the opening periphery outward at the respective ends in the longitudinal direction, and thus bend-align liquid crystal molecules at the curved portions when a voltage is applied. The force caused by this distortion can improve the response speed of liquid crystal molecules.

[0072] In order to align liquid crystal molecules more symmetrically near the periphery of the first opening **15** and the periphery of the second opening **16**, the shapes of the first opening **15** and the second opening **16** each may include linear portions facing each other in the longitudinal direction. In other words, the peripheral shape of the first opening **15** and the peripheral shape of the second opening **16** each may be constituted by linear portions facing each other and two curved portions that link the ends of the linear portions and protrude to the second electrode sides. Further, the shapes of the first opening and the second opening each may include paired protruding. portions in the middle of the respective linear portions. The linear portions preferably have the same length. The angle formed by one of the linear portions facing each other relative to the other linear portion is preferably −2° to +5°, more preferably 0°. The curved portions each have only to partially include a curve, and may have a polygonal shape with at least one corner being rounded. In order to align liquid crystal molecules more symmetrically, the curved portions are preferably circular arcs.

[0073] The presence of the protruding portions **15***a* and **16***a* can stabilize the alignment of liquid crystal molecules when a voltage is applied and immobilize a disclination in the first opening **15** and the second opening **16**, respectively. This seems to result in an improved transmittance and response speed. The presence of the paired protruding portions protruding in the opposite directions seems to allow each of the first opening **15** and the second opening **16** to form four alignment regions symmetrical about the longitudinal direction and the lateral direction of the opening, improving the response speed. In order to form more highly symmetrical four alignment regions, the first opening **15** and the second opening **16** each preferably have a shape symmetrical about the longitudinal direction and the lateral direction of the opening. The peripheral shape of each of the protruding portions **15***a* and **16***a* preferably includes a curved shape, and may be a polygonal shape with at least one corner being rounded. The peripheral shape of each of the protruding portions **15***a* and **16***a* is more preferably a circular arc.

[0074] The protruding portions **15***c* and **16***c* are preferably positioned at a longitudinally middle portion of the first opening **15** and the second opening **16**, respectively. As shown in FIG. **3**, in each of the first opening **15** and the second opening **16**, the straight line linking the vertices of the curved portions and the straight line linking the vertices of the paired protruding portions may be perpendicular to each other. The straight line linking the vertices of the curved portions and the straight line linking the vertices of the paired protruding portions may cross at the middle points thereof.

[0075] The first opening **15** and the second opening **16** each may have a length in the longitudinal direction of 5 μm to 15 μm. The first opening **15** and the second opening **16** each may have a width of 3 μm to 9 μm. The length in the longitudinal direction means the length of the straight line linking the vertices of the curved portions. The width means the length of the straight line linking the vertices of the paired protruding portions. The ratio of the width to the length in the longitudinal direction of each of the first opening **15** and the second opening **16** may be 1 to 5. The first opening **15** and the second opening **16** each having the above size are suitable for high definition with a resolution of 700 ppi (sub pixel 12 μm×36 μm) to 1600 ppi (sub pixel 5.3 μm×15.9 μm).

[0076] The first opening **15** and the second opening **16** are independent of each other and point-symmetrical to each other. The expression "independent of each other" means the first opening **15** and the second opening **16** are not linked with each other and each of them is surrounded by the counter electrode **14**. The expression "point-symmetrical" means the first opening **15** and the second opening **16** overlap 75% or more when one of the openings is inverted about the point of symmetry (center of symmetry). This point-symmetrical arrangement of the first opening **15** and the second opening **16** allows liquid crystal molecules to have symmetrical alignment azimuths in the alignment regions adjacent to each other between the first opening **15** and the second opening **16**. The independent and point-symmetrical arrangement of the first opening **15** and the second opening **16** allows liquid crystal molecules **21** to be divided into four alignment regions in which the alignment azimuths of the liquid crystal molecules **21** are in a rotationally symmetrical relationship in each of the first opening **15** and the second opening **16** in the voltage-applied state where a voltage is applied between the pixel electrode **12** and the counter electrode **14**. There is a crossed dark portion (a region where liquid crystal molecules do not move), i.e., disclination, at the center of the four alignment regions, and these moveless liquid crystal molecules seem to serve as a wall that generates a force in the direction opposite to the rotational direction in each of the four alignment regions, improving the response speed. In the four alignment regions, the alignment azimuths of liquid crystal molecules are preferably in a rotationally symmetrical relationship.

[0077] Since the counter electrode **14** provides a common potential to the respective display units, it may be formed on almost the entire surface (excluding the openings for producing a fringe electric field) of the first substrate **10**. The counter electrode **14** may be electrically connected to an external connecting terminal at the periphery (frame region) of the first substrate **10**.

[0078] As shown in FIG. **4**, the pixel electrode **12** is a planar electrode with no opening. The pixel electrode **12** and the counter electrode **14** are stacked together via the insulating layer **13**. As shown in FIG. **7**, in a plan view, each pixel electrode **12** is positioned under the corresponding first opening **15** and second opening **16** in the counter electrode **14**. Thus, when a potential difference is generated between a pixel electrode **12** and the counter electrode **14**, a fringe electric field is generated around the first opening **15** and the second opening **16** in the counter electrode **14**. Each of the first openings **15** and the second openings **16** preferably entirely overlap the corresponding pixel electrode **12**.

[0079] With reference to FIG. **5** and FIG. **6**, the arrangement of the first opening **15** and the second opening **16** in a display unit of the liquid crystal display device of Embodiment 1 is described below. In FIG. **5** and FIG. **6**, the regions surrounded by bold lines indicate the regions of a display unit (pixel). As shown in FIG. **5** and FIG. **6**, the first opening **15** and the second opening **16** each may have a shape including linear portions in the longitudinal direction. The linear portions of the first opening **15** and the linear portions of the second opening **16** are preferably parallel to each other. The arrangement of the linear portions of the two openings so as to be parallel to each other allows liquid crystal molecules to have symmetrical alignment azimuths between the first opening **15** and the second opening **16**. The first opening **15** and the second opening **16** are preferably arranged in line in the longitudinal direction of a pixel electrode **12**.

[0080] The shortest distance Y is preferably 0.5 μm or greater between the straight line that passes a vertex A and is perpendicular to the bisector **15***c* in the lateral direction of the first opening **15** and the straight line that passes a vertex B and is perpendicular to the bisector **16***c* in the lateral direction of the second opening **16**, where the vertex A represents the vertex of the curved portion closer to the second opening **16** between the curved portions of the first opening **15**, and the vertex B represents the vertex of the curved portion closer to the first opening **15** between the curved portions of the second opening **16**. The openings with a shortest distance Y of smaller than 0.5 μm may be difficult to pattern and the first opening **15** and the second opening **16** may be linked with each other. The shortest distance Y is preferably 4.5 μm or smaller. The openings with a shortest distance Y of greater than 4.5 μm may have no influence on the alignment of liquid crystal molecules between the first opening **15** and the second opening **16**, which may cause too high a transmittance, generating uneven luminance. The bisector **15***c* in the lateral direction of the first opening **15** means, as shown in FIG. **3**, without consideration of the paired protruding portions **15***a*, the bisector between the reference lines **15***b* that link the peripheral portions in the longitudinal direction of the first opening **15**. The bisector **16***c* in the lateral direction of the second opening **16** means, as shown in FIG. **3**, without consideration of the paired protruding portion **16***a*, the bisector between the reference lines **16***b* that link the peripheral portions in the longitudinal direction of the second opening **16**. The vertex of a curved portion means the point that most protrudes to the counter electrode **14** side of the curved portion. The bisector **15***c* in the lateral direction of the first opening **15** preferably passes the vertices of the curved portions of the respective ends in the longitudinal direction of the first opening **15**. The bisector **16***c* in the lateral direction of the second opening **16** preferably passes the vertices of the curved portions of the respective ends in the longitudinal direction of the second opening **16**.

[0081] The distance X may be $1\ \mu m < X \leq 5\ \mu m$ between the vertex A of the curved portion closer to the second opening **16** between the curved portions of the first opening **15** and the vertex B of the curved portion closer to the first opening **15** between the curved portions of the second opening **16**. The distance X within the above range can reduce transmittance variation in one display unit and can reduce occurrence of display unevenness in the display screen of the liquid crystal display device.

[0082] As shown in FIG. **5**, the first opening **15** and the second opening **16** may be arranged in the same straight line. The phrase "arranged in the same straight line" means the bisector **15***c* in the lateral direction of the first opening **15** and the bisector **16***c* in the lateral direction of the second opening **16** are in the same straight line. In this case, the bisectors **15***c* and **16***c* may be parallel to the peripheries in the longitudinal direction of the pixel electrode **12**. The linear portions of the first opening **15** and the linear portions of the second opening **16** may be parallel to the peripheries in the longitudinal direction of the pixel electrode **12**.

[0083] As shown in FIG. **6**, the first opening **15** and the second opening **16** may be arranged not in the same straight line but in an oblique direction. In this case, the pixel electrode **12** may be provided for each pixel, and the long sides of each pixel electrode **12** and at least one of the bisector **15***c* in the lateral direction of the first opening **15** and the bisector **16***c* in the lateral direction of the second opening **16** may form an angle θ**1** of 18° or smaller. The angle θ**1** of 18° or smaller can reduce transmittance variation in one display unit, and can reduce occurrence of display unevenness in the display screen of the liquid crystal display device. At least one of the bisectors **15***c* and **16***c* may be parallel to the longitudinal direction of a pixel.

[0084] The value Z represented by the following formula (1) may be $0.5\ \mu m \leq Z < 2.5\ \mu m$.

$$Z = X - Y \tag{1}$$

[0085] In the formula (1), X represents the distance between the vertex A of the curved portion closer to the second opening between the curved portions of the first opening and the vertex B of the curved portion closer to the first opening between the curved portions of the second opening; and

[0086] Y represents the shortest distance between the straight line that passes the vertex A and is perpendicular to the bisector in the lateral direction of the first opening and the straight line that passes the vertex B and is perpendicular to the bisector in the lateral direction of the second opening.

[0087] The value Z within the above range can reduce transmittance variation in one display unit, and can reduce occurrence of display unevenness in the display screen of the liquid crystal display device.

[0088] The counter electrode **14** has only to be provided with openings at least including the first opening **15** and the second opening **16**, and may be provided with another opening.

[0089] As shown in FIG. **5**, in a plan view, the alignment azimuth (alignment axis) of the liquid crystal molecules in the no-voltage-applied state and the extending direction of the long sides of the pixel electrode **12** may be parallel to each other. In this case, the angle θ**2** is preferably 0° or greater and 1.2° or smaller, where the angle θ**2** represents the angle formed by at least one of the bisector **15***c* in the lateral direction of the first opening **15** and the bisector **16***c* in the lateral direction of the second opening **16** and the alignment azimuth of the liquid crystal molecules in the no-voltage-applied state. The θ**2** is more preferably 0°. As shown in FIG. **6**, when the long sides of the pixel electrode **12** and at least one of the bisector **15***c* in the lateral direction of the first opening **15** and the bisector **16***c* in the lateral direction of the second opening **16** form an angle θ**1**, the alignment axis may be changed in accordance with the angle θ**1**. In the no-voltage-applied state where no voltage is applied between the pixel electrode **12** and the counter electrode **14**, the alignment azimuth of liquid crystal molecules and the extending direction of the long sides of the pixel electrode **12** may be parallel to each other. In this case, the angle θ**2** is preferably θ**1**±1.2°. The initial alignment azimuth of liquid crystal molecules can be given by applying alignment treatment such as rubbing treatment or photo-alignment treatment to the alignment film.

[0090] As shown in FIG. **7**, the drain of a TFT **43** is electrically connected to the corresponding pixel electrode **12**. To the gate of the TFT **43** is electrically connected a gate signal line **42**, and to the source of the TFT **43** is electrically connected a source signal line **41**. Thus, the switching on/off of the TFT **43** is controlled by scanning signals input to the gate signal line **42**. When the TFT **43** is on, data signals (source voltage) input to the source signal line **41** are provided to the pixel electrode **12** through the TFT **43**. As described here, in the voltage-applied state (the on state), a source voltage is applied to the pixel electrode **12** that is a lower layer through the TFT **43**, so that a fringe electric field is generated between the pixel electrode **12** and the counter electrode **14** that is disposed in an upper layer via the insulating film **13**. The TFT **43** preferably has a channel formed from indium-gallium-zinc-oxygen (IGZO) which is an oxide semiconductor. As shown in FIG. **7**, the first openings **15** and the second openings **16** in adjacent display units in the counter electrode **14** are preferably arranged in line in the row direction and/or the column direction. This arrangement can stabilize the alignment of liquid crystal molecules in the voltage-applied state.

[0091] The insulating layer **13** between the pixel electrode **12** and the counter electrode **14** may be, for example, an organic film (dielectric constant ε=3 to 4), an inorganic film (dielectric constant ε=5 to 7) such as a silicon nitride (SiNx) film or a silicon oxide (SiO_2) film, or a multilayer film containing any of these films.

[0092] The liquid crystal molecules **21** may have either a negative or positive value for the anisotropy of dielectric constant (Δε) defined by the formula below. In other words, the liquid crystal molecules **21** may have either negative anisotropy of dielectric constant or positive anisotropy of dielectric constant. Liquid crystal materials containing liquid crystal molecules **21** having negative anisotropy of dielectric constant tend to have a relatively high viscosity. Thus, liquid crystal materials containing liquid crystal molecules **21** having positive anisotropy of dielectric constant are advantageous in order to achieve a high-speed response. Even liquid crystal materials having negative anisotropy of dielectric constant can achieve a similar effect by means of the features of the present embodiment when they have a viscosity as low as that of liquid crystal materials having positive anisotropy of dielectric constant. The initial alignment azimuth of liquid crystal molecules having negative anisotropy of dielectric constant is 90° rotated relative to that of liquid crystal molecules having positive anisotropy of dielectric constant.

[0093] Δε=(dielectric constant in the major axis direction)−(dielectric constant in the minor axis direction)

[0094] In a plan view, the alignment azimuth of liquid crystal molecules **21** in the no-voltage-applied state (the off state) is parallel to the absorption axis of either one of the first polarizer and the second polarizer, and perpendicular to the absorption axis of the other. The control mode of the liquid crystal display device **100** is thus what is called a normally black mode, which provides black display when the liquid crystal layer **20** is in the no-voltage-applied state (the off state).

[0095] The second substrate **30** may be any color filter substrate typically used in the field of liquid crystal display devices. The overcoat layer **33** flattens the liquid crystal layer **20** side surface of the second substrate **30**, and may be an organic film (dielectric constant ε=3 to 4).

[0096] The first substrate **10** and the second substrate **30** are typically bonded to each other with a sealing material applied to surround the periphery of the liquid crystal layer **20**. The first substrate **10**, the second substrate **30**, and the sealing material hold the liquid crystal layer **20** in a predetermined region. Examples of the sealing material include epoxy resins containing inorganic or organic filler and a curing agent.

[0097] The liquid crystal display device **100** may include components such as a backlight; optical films (e.g., a retardation film, a viewing angle-increasing film, and a luminance-increasing film); external circuits (e.g., a tape-carrier package (TCP) and a printed circuit board (PCB)); and a bezel (frame), in addition to the first substrate **10**, liquid crystal layer **20**, and second substrate **30**. These components are not limited, and may be those usually used in the field of liquid crystal display devices. The description of these components is thus omitted.

[0098] The operation of the liquid crystal display device **100** will be described hereinbelow. FIG. **1** shows the no-voltage-applied state (the off state), where no voltage is applied between the pixel electrode **12** and the counter electrode **14**. In the liquid crystal layer **20** in the off state, no electric field is generated and the liquid crystal molecules **21** are aligned parallel to the first substrate **10**, as shown in FIG. **1**. Since the alignment azimuth of the liquid crystal molecules **21** is parallel to the absorption axis of one of the first polarizer and the second polarizer, and since the first polarizer and the second polarizer are disposed in the crossed Nicols, the liquid crystal panel in the off state does not transmit light and provides black display.

[0099] As shown in FIG. **8**(**1**), the alignment azimuth of the liquid crystal molecules **21** in the off state in a plan view may be parallel to the long sides of the pixel electrodes **12**. FIG. **2** shows the voltage-applied state (the on state), where a voltage is applied between the pixel electrode **12** and the counter electrode **14**. In the liquid crystal layer **20** in the on state, an electric field according to the level of the voltage between the pixel electrode **12** and the counter electrode **14** is generated. Specifically, since the openings are formed in the counter electrode **14** arranged closer to the liquid crystal layer than the pixel electrode **12** is, a fringe electric field is generated around the openings. The liquid crystal molecules **21** rotate under the effect of the electric field to change their alignment azimuth from the alignment azimuth in the off state (see FIG. **8**(**1**)) to the alignment azimuths in the on state (see FIG. **8**(**2**)). The liquid crystal panel in the on state thus transmits light to provide white display.

[0100] Each and every detail described for the above embodiment of the present invention shall be applied to all the aspects of the present invention.

[0101] The present invention is described below in more detail based on examples. The examples, however, are not intended to limit the scope of the present invention.

EXAMPLE 1

[0102] A liquid crystal display device of Example 1 is a specific example of the liquid crystal display device **100** of Embodiment 1 and has the following structure.

[0103] For the counter electrode **14** of the liquid crystal display device **100**, the first opening **15** and the second opening **16** were formed so as to have the respective shapes as drawn with the solid lines in FIG. **3**. The bisector **15***c* in the lateral direction of the first opening **15** and the bisector **16***c* in the lateral direction of the second opening **16** were arranged so as to be in the same straight line. As shown in FIG. **5**, the angle θ1 was set to 0° between the long sides of the pixel electrode **12** and each of the bisector **15***c* in the lateral direction of the first opening **15** and the bisector **16***c* in the lateral direction of the second opening **16**. The shortest distance Y was set to 0.5 μm between the straight line that passes the vertex A of the first opening **15** and is perpendicular to the bisector **15***c* in the lateral direction of the first opening **15** and the straight line that passes the vertex B of the first opening **15** and is perpendicular to the bisector **16***c* in the lateral direction of the second opening **16**. The alignment azimuth (alignment axis) of the liquid crystal molecules **21** in the no-voltage-applied state where no voltage is applied between the pixel electrode **12** and the counter electrode **14** is set to be parallel to the linear portions of the first opening **15** and the linear portions of the second opening **16** (angle θ2=0°). For the liquid crystal layer **20**, the refractive index anisotropy (Δn) was set to 0.11, the in-plane retardation (Re) was set to 310 nm, the viscosity was set to 70 cps, and the anisotropy of dielectric constant (Δε) of the liquid crystal molecules **21** was set to 7 (positive). The polarizer was what is called a normally black mode polarizer that provides black display in a state (the off state) where no voltage is applied to the liquid crystal layer **20**. The size of the display unit (sub pixel) was estimated to be 10.5 μm×31.5 μm, and the simulation area was set to 31.5 μm×22.0 μm.

[0104] The distribution of the alignments of liquid crystal molecules in the on state was simulated using LCD-Master 3D (Shintech Inc.), and a simulation photograph per display unit was obtained. The applied voltages for the simulation were 5.0 V at which the alignment state of liquid crystal molecules are likely to be stable and 6.0 V which is a high voltage and thus causes an unstable alignment state of liquid crystal molecules, easily causing transmittance variation. FIG. **9** is an enlarged plan view showing the simulation result of the distribution of the alignments of liquid crystal molecules in the region surrounded by the dotted line in FIG. **8**(**2**). FIG. **10** is a plan view showing the simulation results of Example 1.

[0105] As shown in FIG. **10**, four alignment regions were formed in the 45° directions from the center of each of the first opening **15** and the second opening **16**, and thus eight alignment regions were present in one display unit. For each of the first opening **15** and the second opening **16**, liquid crystal molecules were aligned in the 45° directions from the center of the opening and were sufficiently rotated in an early stage of voltage application. Thus, a high transmittance was achieved. In the four alignment regions formed for each of the first opening **15** and the second opening **16**, liquid crystal molecules are bend-aligned. The force caused by this distortion allows liquid crystal molecules to respond rapidly. The presence of the protruding portions in each of the first opening **15** and the second opening **16** enables maintenance of the symmetry of the four alignment regions even at a high voltage (6.0 V), leading to rapid performance. As shown in FIG. **9**, liquid crystal molecules were symmetrically aligned even between the first opening **15** and the second opening **16**. This demonstrates that the transmittance is high and the alignment is stable.

EXAMPLE 2 to EXAMPLE 4

[0106] Liquid crystal display devices of Examples 2 to 4 each have the same structure as the liquid crystal display device of Example 1, except that the distance Y was changed to 1.5 μm, 2.5 μm, and 4.5 μm, respectively. Simulation was performed at a distance Y of 1.5 μm, as a reference, as well as at 0.5 μm, and 2.5 μm, in consideration of variations among production steps. Also, the case of Y=4.5 μm, was simulated at which the alignment regions are less likely to be affected by each other at the boundary between the adjacent first opening **15** and second opening **16**.

[0107] The liquid crystal display devices of Examples 2 to 4 were also subjected to simulations at applied voltages of 5.0 V and of 6.0 V in the same manner as in Example 1. FIG.

[0108] **11** is a table showing the simulation results of Examples 1 to 4. The cases where the transmittance difference was lower than 1% were evaluated as excellent, the transmittance difference of 1% or higher and lower than 1.5% as good, and the transmittance difference of 1.5% or higher as fair. The transmittance difference indicates the difference calculated as follows: applying a voltage of 5.0 V or 6.0 V to the liquid crystal display device of Example 2 (Y=1.5 μ, θ1=0°, θ2=0°); calculating the transmittance of each example at a gray scale value of 255, with the transmittance at a gray scale value of 255 for each voltage taken as a reference (100%); and subtracting the calculated value from 100%. A transmittance difference of lower than 1% corresponds to a gray scale difference of lower than 1; a transmittance difference of 1% or higher and lower than 1.5% corresponds to a gray scale difference of 1 or higher and lower than 2; and a transmittance difference of 1.5% or higher corresponds to a gray scale difference of 2 or higher. A gray scale difference of lower than 2 is less likely to be observed as luminance unevenness. The gray scale difference indicates the difference between the gray scale value of Example 2 (Y=1.5 μ, θ1=0°, θ2=0°, 5.0 V or 6.0 V applied) and the gray scale value of each example obtained at a gray scale value of 255 with a voltage of 5.0 V or 6.0 V applied thereto.

EXAMPLE 5

[0109] FIG. **12** is a schematic plan view of a display unit in a liquid crystal display device of Example 5. The liquid crystal display device of Example 5 has the same structure as the liquid crystal display device of Example 1, except that the angle θ**1** was changed to 2°.

EXAMPLE 6 to EXAMPLE 8

[0110] Liquid crystal display devices of Examples 6 to 8 each have the same structure as the liquid crystal display device of Example 5, except that the distance Y was changed to 1.5 μm, 2.5 μm, and 4.5 μm, respectively.

[0111] The liquid crystal display devices of Examples 5 to 8 were subjected to simulations at applied voltages of 5.0 V and 6.0 V and evaluated in the same manner as in Example 1. FIG. **13** is a table showing the simulation results in a display unit of Examples 5 to 8.

EXAMPLE 9

[0112] FIG. **14** is a schematic plan view of a display unit in a liquid crystal display device of Example 9. A liquid crystal display device of Example 9 has the same structure as the liquid crystal display device of Example 1, except that the angle θ**1** was changed to 4°.

EXAMPLE 10 to EXAMPLE 12

[0113] Liquid crystal display devices of Examples 10 to 12 each have the same structure as the liquid crystal display device of Example 9, except that the distance Y was changed to 1.5 μm, 2.5 μm, and 4.5 μm, respectively.

[0114] The liquid crystal display devices of Examples 9 to 12 were subjected to simulations at applied voltages of 5.0 V and 6.0 V and evaluated in the same manner as in Example 1. FIG. **15** is a table showing the simulation results of Examples 9 to 12.

EXAMPLE 13

[0115] FIG. **16** is a schematic plan view of a display unit in a liquid crystal display device of Example 13. A liquid crystal display device of Example 13 has the same structure as the liquid crystal display device of Example 1, except that the angle θ**1** was changed to 5°.

EXAMPLE 14 to EXAMPLE 16

[0116] Liquid crystal display devices of Examples 14 to 16 each have the same structure as the liquid crystal display device of Example 13, except that the distance Y was changed to 1.5 μm, 2.5 μm, and 4.5 μm, respectively.

[0117] The liquid crystal display devices of Examples 13 to 16 were subjected to simulations at applied voltages of 5.0 V and 6.0 V and evaluated in the same manner as in Example 1. FIG. **17** is a table showing the simulation results of Examples 13 to 16.

EXAMPLE 17

[0118] FIG. **18** is a schematic plan view of a display unit in a liquid crystal display device of Example 17. A liquid crystal display device of Example 17 has the same structure as the liquid crystal display device of Example 1, except that the angle θ**1** was changed to 6°.

EXAMPLE 18 to EXAMPLE 20

[0119] Liquid crystal display devices of Examples 18 to 20 each have the same structure as the liquid crystal display device of Example 17, except that the distance Y was changed to 1.5 μm, 2.5 μm, and 4.5 μm, respectively.

[0120] The liquid crystal display devices of Examples 17 to 20 were subjected to simulations at applied voltages of 5.0 V and 6.0 V and evaluated in the same manner as in Example 1. FIG. **19** is a table showing the simulation results of Examples 17 to 20.

EXAMPLE 21

[0121] FIG. **20** is a schematic plan view of a display unit in a liquid crystal display device of Example 21. A liquid crystal display device of Example 21 has the same structure as the liquid crystal display device of Example 1, except that the angle θ**1** was changed to 7°.

EXAMPLE 22 to EXAMPLE 24

[0122] Liquid crystal display devices of Examples 22 to 24 each have the same structure as the liquid crystal display device of Example 21, except that the distance Y was changed to 1.5 μm, 2.5 μm, and 4.5 μm, respectively.

[0123] The liquid crystal display devices of Examples 21 to 24 were subjected to simulations at applied voltages of 5.0 V and 6.0 V and evaluated in the same manner as in Example 1. FIG. **21** is a table showing the simulation results of Examples 21 to 24.

EXAMPLE 25

[0124] FIG. **22** is a schematic plan view of a display unit in a liquid crystal display device of Example 25. A liquid crystal display device of Example 25 has the same structure as the liquid crystal display device of Example 1, except that the angle θ**1** was changed to 8°.

EXAMPLE 26 to EXAMPLE 28

[0125] Liquid crystal display devices of Examples 26 to 28 each have the same structure as the liquid crystal display device of Example 25, except that the distance Y was changed to 1.5 μm, 2.5 μm, and 4.5 μm, respectively.

[0126] The liquid crystal display devices of Examples 25 to 28 were subjected to simulations at applied voltages of 5.0 V and 6.0 V and evaluated in the same manner as in Example 1. FIG. **23** is a table showing the simulation results of Examples 25 to 28.

EXAMPLE 29

[0127] FIG. **24** is a schematic plan view of a display unit in a liquid crystal display device of Example 29. A liquid crystal display device of Example 29 has the same structure as the liquid crystal display device of Example 1, except that the angle θ**1** was changed to 10°.

EXAMPLE 30 to EXAMPLE 32

[0128] Liquid crystal display devices of Examples 30 to 32 each have the same structure as the liquid crystal display device of Example 29, except that the distance Y was changed to 1.5 μm, 2.5 μm, and 4.5 μm, respectively.

[0129] The liquid crystal display devices of Examples 29 to 32 were subjected to simulations at applied voltages of 5.0 V and 6.0 V and evaluated in the same manner as in Example 1. FIG. **25** is a table showing the simulation results of Examples 29 to 32.

EXAMPLE 33

[0130] FIG. **26** is a schematic plan view of a display unit in a liquid crystal display device of Example 33. A liquid crystal display device of Example 33 has the same structure as the liquid crystal display device of Example 1, except that the angle θ**1** was changed to 14°.

EXAMPLE 34 to EXAMPLE 36

[0131] Liquid crystal display devices of Examples 34 to 36 each have the same structure as the liquid crystal display device of Example 33, except that the distance Y was changed to 1.5 μm, 2.5 μm, and 4.5 μm, respectively.

[0132] The liquid crystal display devices of Examples 33 to 36 were subjected to simulations at applied voltages of 5.0 V and 6.0 V and evaluated in the same manner as in Example 1. FIG. **27** is a table showing the simulation results of Examples 33 to 36.

EXAMPLE 37

[0133] FIG. **28** is a schematic plan view of a display unit in a liquid crystal display device of Example 37. A liquid crystal display device of Example 37 has the same structure as the liquid crystal display device of Example 1, except that the angle θ**1** was changed to 20°.

EXAMPLE 38 to EXAMPLE 40

[0134] Liquid crystal display devices of Examples 38 to 40 each have the same structure as the liquid crystal display device of Example 37, except that the distance Y was changed to 1.5 μm, 2.5 μm, and 4.5 μm, respectively.

[0135] The liquid crystal display devices of Examples 37 to 40 were subjected to simulations at applied voltages of 5.0 V and 6.0 V and evaluated in the same manner as in Example 1. FIG. **29** is a table showing the simulation results of Examples 37 to 40.

[0136] In the following Examples 41 to 50, the angle θ**2** was changed in accordance with the angle θ**1** so as to make the alignment azimuth (alignment axis) of liquid crystal molecules parallel to the extending direction of the long sides of the pixel electrode.

EXAMPLE 41

[0137] A liquid crystal display device of Example 41 has the same structure as the liquid crystal display device of Example 1 with $\theta 1 = \theta 2 = 0°$, except that the distance Y was changed to 2.5 μm.

EXAMPLE 42 to EXAMPLE 50

[0138] Liquid crystal display devices of Examples 42 to 50 each have the same structure as the liquid crystal display device of Example 41, except that the angle θ**1** and the angle θ**2** were changed to 2°, 4°, 5°, 6°, 7°, 8°, 10°, 14°, and 20°, with the angle θ**1**=the angle θ**2**.

[0139] The liquid crystal display devices of Examples 41 to 50 were subjected to simulations at applied voltages of 5.0 V and 6.0 V and evaluated in the same manner as in Example 1. FIG. **30** is a table showing the simulation results of Examples 41 to 43. FIG. **31** is a table showing the simulation results of Examples 44 to 46. FIG. **32** is a table showing the simulation results of Examples 47 to 50.

[0140] Each of the examples provided a liquid crystal display device in which four alignment regions in positions rotationally symmetrical to each other were formed for each of the first opening **15** and the second opening **16** in the voltage-applied state. This demonstrates that the presence of the first opening **15** and the second opening **16** in high-definition pixels enables control of the alignment of liquid crystal molecules, providing a liquid crystal display device that achieves both a high transmittance and a high response speed of liquid crystal molecules.

[0141] The present inventors have focused on the fact that luminance unevenness may be observed in the display screen of a liquid crystal display device when the distance Y, the angle θ**1**, and the θ**2** are changed. The present inventors performed studies on occurrence of luminance unevenness, and found that luminance unevenness occurs due to the presence of the first opening **15** and the second opening **16** adjacent to each other in the counter electrode **14**. In this case, liquid crystal molecules conflict with each other at the boundary of adjacent alignment regions between the first opening **15** and the second opening **16**, and the alignments of liquid crystal molecules become uneven and the transmittance was changed. Thereby, luminance unevenness occurs.

[0142] In production of the first opening **15** and the second opening **16** in the counter electrode **14**, an error of about ±1 μm, may occur in parameters such as the distance between the first opening **15** and the second opening **16** and the peripheral shapes. In order to examine the influence of such an error in the production, the distance Y, the angle θ**1**, and the angle θ**2** were changed and transmittance variation in one display unit was observed.

[0143] At first, changes of the transmittance in accordance with changes of the distance Y were examined. With reference to FIG. **33** to FIG. **36**, Examples 9 to 12 are taken as examples in which the angle θ**1** was set to 4°, the angle θ**2** was set to 0°, and the distance Y was changed. FIG. **33** is a plan view showing the simulation results of Example 9. FIG. **34** is a plan view showing the simulation results of Example 10. FIG. **35** is a plan view showing the simulation results of Example 11. FIG. **36** is a plan view showing the simulation results of Example 12.

[0144] Comparison of FIG. **33** to FIG. **36** shows that the narrower the distance Y is, the more the alignment regions adjacent to each other between the first opening **15** and the second opening **16** among the four alignment regions formed for each opening are affected by each other. In Example 9 (FIG. **33**) where the first opening **15** and the second opening **16** are too close to each other, the alignment regions adjacent to each other between the openings were slightly oblique as surrounded by the dotted line. Thus, the transmittance in Example 9 was low and the gray scale value fell within the range of 1 to 2 at which luminance unevenness is likely to be observed. FIG. **33** to FIG. **36** also show that the wider the distance Y is, the less the alignment regions adjacent to each other between the openings are affected by each other, and thus the higher the transmittance is. In contrast, in Example 12 (FIG. **36**), no influence was exerted on the alignments of liquid crystal molecules between the first opening **15** and the second opening **16**. Thus, the transmittance is too high.

[0145] Accordingly, on the basis of Example 2 (Y=1.5 μ, $\theta 1 = 0°$, $\theta 2 = 0°$, 6.0 V applied), the transmittance difference exceeded 1.5% and thus luminance unevenness was observed.

[0146] Next, changes of the transmittance in accordance with changes of the angle θ**1** were examined. With reference to FIG. **37** to FIG. **43**, the examples in which the angle θ**2** was set to 0°, the distance Y was set to 1.5 μm, or 2.5 μm, and the angle θ**1** was changed are taken as examples. FIG. **37** is a plan view showing the simulation results of Example 2. FIG. **38** is a plan view showing the simulation results of Example 38. FIG. **39** is a plan view showing the simulation results of Example 3. FIG. **40** is a plan view showing the simulation results of Example 35. FIG. **41** is a plan view showing the simulation results of Example 39. FIG. **42** is a plan view showing the simulation results of Example 48. FIG. **43** is a plan view showing the simulation results of Example 50.

[0147] Comparison between Example 2 (FIG. **37**) and Example 38 (FIG. **38**) shows that, with the distance Y=1.5 μm, and the angle $\theta 2 = 0°$, smaller proportions of the alignment regions adjacent to each other between the openings are affected by each other, and thus the transmittance is less changed even when the angle θ**1** is changed. This is presumably because as follows. That is, the above distance Y is appropriate to the alignment regions adjacent to each other between the openings and, even when the angle θ**1** was changed, the conflict between the liquid crystal molecules exerts a balanced influence on the alignment regions adjacent to each other between the openings, so that the transmittance is less likely to change.

[0148] Comparison of Example 3 (FIG. **39**), Example 35 (FIG. **40**), and Example 39 (FIG. **41**) shows that, with the distance Y=2.5 μm, and the angle $\theta 2 = 0°$, which means the alignment regions adjacent to each other between the openings are apart from each other, the transmittance is excessively reduced as the angle θ**1** is changed; specifically, the transmittance is 1.5% or more lower than that of Example 2 (Y=1.5 μ, $\theta 1 = 0°$, $\theta 2 = 0°$, 6.0 V applied).

[0149] Comparison of Example 3 (FIG. **39**), Example 48 (FIG. **42**), and Example 50 (FIG. **43**) shows as follows. That is, with the distance Y=2.5 μm, a change of the angle θ**1** from 0° to 10° or 20° and the corresponding change of the angle θ**2** from 0° to 10° or 20° so as to achieve θ**1**=θ**2** disturb the balance of the alignments of liquid crystal molecules among the four alignment regions formed for each of the first opening **15** and the second opening **16**, and further greatly change the balance between the alignment regions adjacent to each other between the openings. This means the transmittance will be greatly changed when the bisectors **15***c* and **16***c* in the lateral direction of the first opening **15** and the second opening **16** and the alignment azimuths (polarization axes) of liquid crystal molecules are misaligned.

[0150] Further, the transmittance performance in accordance with changes in the angle θ**1** at an applied voltage of 5.0 V and 6.0 V was examined. FIG. **44** is a graph showing the relationship between the angle θ**1** and the transmittance at an applied voltage of 5.0 V. FIG. **45** is a graph showing the relationship between the angle θ**1** and the transmittance at an applied voltage of 6.0 V. In each graph, the horizontal axis shows the angle θ**1**) (°) and the vertical axis shows the transmittance (%). The transmittance is a value at a gray scale value of 225 in the liquid crystal display device of each example. In FIG. **44**, the transmittance (9.28%) of Example 2 (5.0 V) circled was used as a reference. In FIG. **45**, the transmittance (10.19%) of Example 2 (6.0 V) circled was used as a reference. The transmittance variation in each example was examined within the range of ±1.0% and within the range of ±1.5%. In FIG. **44** and FIG. **45**, the explanatory note "Y=2.5 μm+θ**2** changed" means the distance Y was set to 2.5 μm, and the polarization axis was changed so as to achieve θ**1**=θ**2**. This corresponds to Examples 41 to 50. The other explanatory notes correspond to the cases where the angle θ**2** was set to 0° and the angle θ**1** was changed with the distance Y=0.5 μm, 1.5 μm, 2.5 μm, and 4.5 μm.

[0151] Comparison between FIG. **44** and FIG. **45** shows that the transmittance varies widely when the applied voltage is changed from 5.0 V to 6.0 V. This is presumably because as follows. That is, a high applied voltage may cause a great conflict between the alignments of liquid crystal molecules between the first opening **15** and the second opening **16**. This conflict may disturb the balance among the four alignment regions formed for each of the first opening **15** and the second opening **16**, greatly affecting the transmittance. FIG. **44** and FIG. **45** demonstrate that, in order to reduce transmittance variation in one display unit and to reduce occurrence of display unevenness in the display screen of the liquid crystal display device, the angle θ**1** is preferably 18° or smaller.

[0152] The relationship between the distance (X) between the vertices of the openings and the angle θ**1** is shown in FIG. **46**. The distance X is the distance between the vertex A of the curved portion closer to the second opening **16** between the curved portions of the first opening **15** and the vertex B of the curved portion closer to the first opening **15** between the curved portions of the second opening **16**. FIG. **46** is a graph showing the relationship between the distance

[0153] (X) between the vertices of the openings and the angle θ**1**. In FIG. **46**, the horizontal axis shows the angle θ**1** (°) and the vertical axis shows the distance X (μm). FIG. **46** demonstrates that, with a distance Y of any of 0.5 μm, 1.5 μm, 2.5 μm, and 4.5 μm, the distance X correlatively increases as the angle θ**1** increases.

[0154] The relationship between the distance X shown in FIG. **46** and the transmittance of each example is shown in FIG. **47** and FIG. **48**. FIG. **47** is a graph showing the relationship between the distance (X) between the vertices of the openings and the transmittance at an applied voltage of 5.0 V. FIG. **48** is a graph showing the relationship between the distance (X) between the vertices of the openings and the transmittance at an applied voltage of 6.0 V. In FIG. **47**, the transmittance (9.28%) of Example 2 (5.0 V) was used as a reference. In FIG. **45**, the transmittance (10.19%) of Example 2 (6.0 V) was used as a reference. The transmittance variation in each example was examined within the range of ±1.0% and within the range of ±1.5%. FIG. **47** and FIG. **48** demonstrate that the transmittance difference is 1.0% or lower (dark gray area) when the distance X is 1.5 μm, or greater and 4.0 μm, or smaller, and the transmittance difference is 1.5% or lower (light gray area) when the distance X is 1 μm<X≤5 μm. The figures also demonstrate that the slope of the graph increases and the transmittance is more greatly changed as the distance Y is increased from 0.5 μm, to 4.5 μm. The figures also demonstrate that the slope of the graph increases and the transmittance is more greatly changed also when the angle θ**1** is increased and the angle θ**2** (alignment axis) is changed so as to be parallel to the angle θ**1**. Accordingly, in order to reduce transmittance variation in one display unit and to reduce occurrence of display unevenness in the display screen of the liquid crystal display device, the distance X is preferably 1 μm<X≤5 μm. The distance X is more preferably 1.5 μm, or greater and 4.0 μm, or smaller.

[0155] The relationship between the value (Z) obtained by subtracting the distance Y from the distance X and the transmittance is shown in FIG. **49** and FIG. **50**. FIG. **49** is a graph showing the relationship between the value Z and the transmittance at an applied voltage of 5.0 V. FIG. **50** is a graph showing the relationship between the value Z and the transmittance at an applied voltage of 6.0 V. In FIG. **49**, the transmittance (9.28%) of Example 2 (5.0 V) was used as a reference. In FIG. **50**, the transmittance (10.19%) of Example 2 (6.0 V) was used as a reference. The transmittance variation in each example was examined within the range of ±1.0% and within the range of ±1.5%. As shown in FIG. **49** and FIG. **50**, with a wide distance Y (e.g., Y=4.5 μm,) and with a narrow distance Y (e.g., Y=0.5 μm), the transmittance variation is large with the value Z<0.5. In contrast, the figures demonstrate that the transmittance is stable with 0.5 μm≤Z<2.5 μm. Accordingly, in order to reduce transmittance variation in one display unit and to reduce occurrence of display unevenness in the display screen of the liquid crystal display device, the value Z is preferably 0.5 μm≤Z<2.5 μm.

[0156] The distances Y, the angles θ**1**, the distances X, and the values Z in Examples 1 to 50 are listed in Table 1.

TABLE 1

	Example 1	Example 2	Example 3	Example 4	Example 5	Example 6	Example 7	Example 8
Y (μm)	0.5	1.5	2.5	4.5	0.5	1.5	2.5	4.5
θ1 (°)	0	0	0	0	2	2	2	2
X (μm)	0.5	1.5	2.5	4.5	0.7	1.6	2.5	4.5
Z (μm)	0	0	0	0	0.2	0.1	0.0	0.0

TABLE 1-continued

	Example 9	Example 10	Example 11	Example 12	Example 13	Example 14	Example 15	Example 16
Y (μm)	0.5	1.5	2.5	4.5	0.5	1.5	2.5	4.5
θ1 (°)	4	4	4	4	5	5	5	5
X (μm)	1.0	1.7	2.7	4.6	1.1	1.9	2.8	4.7
Z (μm)	0.5	0.2	0.2	0.1	0.6	0.4	0.3	0.2

	Example 17	Example 18	Example 19	Example 20	Example 21	Example 22	Example 23	Example 24
Y (μm)	0.5	1.5	2.5	4.5	0.5	1.5	2.5	4.5
θ1 (°)	6	6	6	6	7	7	7	7
X (μm)	1.3	2.0	2.9	4.8	1.5	2.1	3.0	4.9
Z (μm)	0.8	0.5	0.4	0.3	1.0	0.6	0.5	0.4

	Example 25	Example 26	Example 27	Example 28	Example 29	Example 30	Example 31	Example 32
Y (μm)	0.5	1.5	2.5	4.5	0.5	1.5	2.5	4.5
θ1 (°)	8	8	8	8	10	10	10	10
X (μm)	1.7	2.2	3.2	5.0	2.1	2.7	3.5	5.3
Z (μm)	1.2	0.7	0.7	0.5	1.6	1.2	1.0	0.8

	Example 33	Example 34	Example 35	Example 36	Example 37	Example 38	Example 39	Example 40
Y (μm)	0.5	1.5	2.5	4.5	0.5	1.5	2.5	4.5
θ1 (°)	14	14	14	14	20	20	20	20
X (μm)	2.8	3.5	4.2	5.9	4.2	4.8	5.5	7.2
Z (μm)	2.3	2.0	1.7	1.4	3.7	3.3	3.0	2.7

	Example 41	Example 42	Example 43	Example 44	Example 45	Example 46	Example 47	Example 48
Y (μm)	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
θ1 (°)	0	2	4	5	6	7	8	10
X (μm)	2.5	2.5	2.7	2.8	2.9	3.0	3.2	3.5
Z (μm)	0	0.0	0.2	0.3	0.4	0.5	0.7	1.0

	Example 49	Example 50
Y (μm)	2.5	2.5
θ1 (°)	14	20
X (μm)	4.2	5.5
Z (μm)	1.7	3.0

[0157] [Additional Remarks]

[0158] One aspect of the present invention may be a liquid crystal display device including, in the given order: a first substrate; a liquid crystal layer containing liquid crystal molecules; and a second substrate, the first substrate including a first electrode, a second electrode closer to the liquid crystal layer than the first electrode is, and an insulating film between the first electrode and the second electrode, the second electrode being provided with openings including a first opening and a second opening adjacent to each other, the first opening and the second opening being independent of each other and point-symmetrical to each other, the first opening and the second opening each having a shape including: curved portions that expand an opening periphery outward at the respective ends in the longitudinal direction; and paired protruding portions that allow the opening periphery to protrude partially in the lateral direction in the middle of the longitudinal direction, the liquid crystal molecules being aligned parallel to the first substrate in a no-voltage-applied state where no voltage is applied between the first electrode and the second electrode.

[0159] The shape of each of the first opening and the second opening each may include a linear portion in the longitudinal direction, and the linear portion of the first opening and the linear portion of the second opening may be parallel to each other.

[0160] The shortest distance may be 0.5 μm, or greater and 4.5 μm, or smaller between the straight line that passes a vertex A and is perpendicular to the bisector in the lateral direction of the first opening and the straight line that passes a vertex B and is perpendicular to the bisector in the lateral direction of the second opening, where the vertex A represents the vertex of the curved portion closer to the second opening between the curved portions of the first opening, and the vertex B represents the vertex of the curved portion closer to the first opening between the curved portions of the second opening.

[0161] The distance X may be $1\ \mu m < X \leq 5\ \mu m$ between the vertex A of the curved portion closer to the second opening between the curved portions of the first opening and the vertex B of the curved portion closer to the first opening between the curved portions of the second opening.

[0162] The value Z represented by the following formula (1) may be $0.5\ \mu m \leq Z < 2.5\ \mu m$,

$$Z = X - Y \tag{1}$$

wherein X is the distance between the vertex A of the curved portion closer to the second opening between the curved portions of the first opening and the vertex B of the curved portion closer to the first opening between the curved portions of the second opening, and

[0163] Y is the shortest distance between the straight line that passes the vertex A and is perpendicular to the bisector in the lateral direction of the first opening and the straight line that passes the vertex B and is perpendicular to the bisector in the lateral direction of the second opening.

[0164] The first electrode may be provided for each pixel, and the alignment azimuth of the liquid crystal molecules and the extending direction of the long sides of the first electrode may be parallel to each other in the no-voltage-applied state where no voltage is applied between the first electrode and the second electrode.

[0165] The first electrode may be provided for each pixel, and the long sides of the first electrode and at least one of the bisector in the lateral direction of the first opening and the bisector in the lateral direction of the second opening may form an angle of 18° or smaller.

[0166] The liquid crystal molecules may have positive anisotropy of dielectric constant.

[0167] The liquid crystal molecules may be divided into four alignment regions in positions rotationally symmetrical to each other for each of the first opening and the second opening in a voltage-applied state where a voltage is applied between the first electrode and the second electrode.

[0168] Each of the aforementioned features of the present invention may be combined as appropriate within the spirt of the present invention.

REFERENCE SIGNS LIST

[0169] **10**: First substrate
[0170] **11**: Insulating substrate
[0171] **12**: Pixel electrode (first electrode)
[0172] **13**: Insulating layer (insulating film)
[0173] **14**: Common electrode (second electrode)
[0174] **15**: First opening
[0175] **16**: Second opening
[0176] **15***a*: Protruding portion of first opening
[0177] **16***a*: Protruding portion of second opening
[0178] **15***b*: Reference line of first opening
[0179] **16***b*: Reference line of second opening
[0180] **15***c*: Bisector in lateral direction of first opening
[0181] **16***c*: Bisector in lateral direction of second opening
[0182] **20**: Liquid crystal layer
[0183] **21**: Liquid crystal molecules
[0184] **30**: Second substrate
[0185] **31**: Insulating substrate
[0186] **32**: Color filter
[0187] **33**: Overcoat layer
[0188] **41**: Source signal line
[0189] **42**: Gate signal line
[0190] **43**: TFT
[0191] **100**: Liquid crystal display device

1. A liquid crystal display device comprising, in the given order:
a first substrate;
a liquid crystal layer containing liquid crystal molecules; and
a second substrate,
the first substrate including a first electrode, a second electrode closer to the liquid crystal layer than the first electrode is, and an insulating film between the first electrode and the second electrode,
the second electrode being provided with openings including a first opening and a second opening adjacent to each other,
the first opening and the second opening being independent of each other and point-symmetrical to each other,
the first opening and the second opening each having a shape including: curved portions that expand an opening periphery outward at the respective ends in the longitudinal direction; and
paired protruding portions that allow the opening periphery to protrude partially in the lateral direction in the middle of the longitudinal direction,
the liquid crystal molecules being aligned parallel to the first substrate in a no-voltage-applied state where no voltage is applied between the first electrode and the second electrode.

2. The liquid crystal display device according to claim **1**, wherein the shape of each of the first opening and the second opening includes a linear portion in the longitudinal direction, and
the linear portion of the first opening and the linear portion of the second opening are parallel to each other.

3. The liquid crystal display device according to claim **1**, wherein the shortest distance is 0.5 μm or greater and 4.5 μm or smaller between the straight line that passes a vertex A and is perpendicular to the bisector in the lateral direction of the first opening and the straight line that passes a vertex B and is perpendicular to the bisector in the lateral direction of the second opening,
where the vertex A represents the vertex of the curved portion closer to the second opening between the curved portions of the first opening, and the vertex B represents the vertex of the curved portion closer to the first opening between the curved portions of the second opening.

4. The liquid crystal display device according to claim **1**, wherein the distance X is $1\ \mu m < X \leq 5\ \mu m$ between the vertex A of the curved portion closer to the second opening between the curved portions of the first opening and the vertex B of the curved portion closer to the first opening between the curved portions of the second opening.

5. The liquid crystal display device according to claim **1**, wherein the value Z represented by the following formula (1) is $0.5\ \mu m \leq Z < 2.5\ \mu m$,

$$Z = X - Y \quad (1)$$

wherein X is the distance between the vertex A of the curved portion closer to the second opening between the curved portions of the first opening and the vertex B of the curved portion closer to the first opening between the curved portions of the second opening, and
Y is the shortest distance between the straight line that passes the vertex A and is perpendicular to the bisector in the lateral direction of the first opening and the straight line that passes the vertex B and is perpendicular to the bisector in the lateral direction of the second opening,

6. The liquid crystal display device according to claim **1**, wherein the first electrode is provided for each pixel, and
the alignment azimuth of the liquid crystal molecules and the extending direction of the long sides of the first electrode are parallel to each other in the no-voltage-applied state where no voltage is applied between the first electrode and the second electrode.

7. The liquid crystal display device according to claim **1**, wherein the first electrode is provided for each pixel, and
the long sides of the first electrode and at least one of the bisector in the lateral direction of the first opening and

the bisector in the lateral direction of the second opening form an angle of 18° or smaller.

8. The liquid crystal display device according to claim **1**, wherein the liquidmolecules have positive anisotropy of dielectric constant.

9. The liquid crystal display device according to claim **1**, wherein the liquid crystal molecules are divided into four alignment regions in positions rotationally symmetrical to each other for each of the first opening and the second opening in a voltage-applied state where a voltage is applied between the first electrode and the second electrode.

* * * * *

patsnap

专利名称(译)	液晶显示装置		
公开(公告)号	US20190086744A1	公开(公告)日	2019-03-21
申请号	US16/085111	申请日	2017-03-07
[标]申请(专利权)人(译)	夏普株式会社		
申请(专利权)人(译)	夏普株式会社		
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[标]发明人	MURATA MITSUHIRO IWATA YOSUKE TOMOTOSHI TAKUMA		
发明人	MURATA, MITSUHIRO IWATA, YOSUKE TOMOTOSHI, TAKUMA		
IPC分类号	G02F1/1343 G02F1/1333 G02F1/1337		
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摘要(译)

本发明的液晶显示装置按照给定的顺序包括：第一基板;含有液晶分子的液晶层;和第二基板。第一基板包括第一电极，比第一电极更靠近液晶层的第二电极，以及第一电极和第二电极之间的绝缘膜。第二电极设置有开口，所述开口包括彼此相邻的第一开口和第二开口。第一开口和第二开口彼此独立并且彼此点对称。第一开口和第二开口各自具有包括：弯曲部分的形状，该弯曲部分在纵向方向上的各个端部处向外扩展开口周边;成对的突出部分允许开口周边在纵向方向的中间部分地沿横向突出。在未施加电压的状态下，液晶分子平行于第一基板排列，其中在第一电极和第二电极之间没有施加电压。