



US007920239B2

(12) **United States Patent**  
**Nakanishi et al.**

(10) **Patent No.:** **US 7,920,239 B2**  
(45) **Date of Patent:** **Apr. 5, 2011**

(54) **LIQUID CRYSTAL DISPLAY DEVICE**

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

(21) Appl. No.: **12/785,215**

(22) Filed: **May 21, 2010**

(65) **Prior Publication Data**

US 2011/0001913 A1 Jan. 6, 2011

**Related U.S. Application Data**

(62) Division of application No. 12/723,977, filed on Mar. 15, 2010, which is a division of application No. 11/104,309, filed on Apr. 12, 2005, now Pat. No. 7,710,523.

(30) **Foreign Application Priority Data**

Jan. 6, 2005 (JP) ..... 2005-001356

(51) **Int. Cl.**

**G02F 1/1337** (2006.01)

**G02F 1/1343** (2006.01)

(52) **U.S. Cl.** ..... 349/129; 349/143; 349/139; 349/39

(58) **Field of Classification Search** ..... 349/129, 349/143

See application file for complete search history.

(56) **References Cited**

**U.S. PATENT DOCUMENTS**

|              |    |        |                 |
|--------------|----|--------|-----------------|
| 5,724,111    | A  | 3/1998 | Mizobata et al. |
| 6,747,712    | B2 | 6/2004 | Noh et al.      |
| 6,850,302    | B2 | 2/2005 | Song            |
| 7,113,241    | B2 | 9/2006 | Hanaoka         |
| 7,379,143    | B2 | 5/2008 | Lyu             |
| 2002/0075437 | A1 | 6/2002 | Fukumoto et al. |
| 2003/0043336 | A1 | 3/2003 | Sasaki et al.   |
| 2003/0058374 | A1 | 3/2003 | Takeda et al.   |
| 2003/0071952 | A1 | 4/2003 | Yoshida et al.  |
| 2003/0137628 | A1 | 7/2003 | Nagaoka         |
| 2003/0160750 | A1 | 8/2003 | Ueda et al.     |

(Continued)

**FOREIGN PATENT DOCUMENTS**

JP 5-232465 9/1993

(Continued)

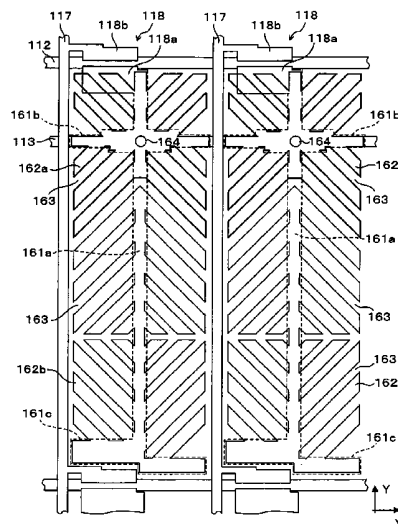
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(57) **ABSTRACT**

A liquid crystal display device including first and second substrates, liquid crystal between the substrates, a plurality of gate bus lines extending in a first direction, a plurality of drain bus lines extending in a second direction, and a picture element electrode. The picture element electrode includes a body portion and a plurality of branches, separated by slits, extending therefrom. The body portion includes a first body portion extending generally in the first direction and a second body portion extending generally in the second direction, and further wherein the first body portion includes at least one wide portion and at least one narrow portion. The liquid crystal display device also includes a capacitor electrode and a capacitor upper electrode that overlap the wide portion. The capacitor upper electrode connects to the picture element electrode through a contact hole formed at the wide portion.

**2 Claims, 33 Drawing Sheets**



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|                       |          |            |                          |              |         |
|-----------------------|----------|------------|--------------------------|--------------|---------|
| U.S. PATENT DOCUMENTS |          |            | JP                       | 2002-169159  | 6/2002  |
| 2005/0078253 A1       | 4/2005   | Kim et al. | JP                       | 2003-149647  | 5/2003  |
|                       |          |            | JP                       | 2003-156731  | 5/2003  |
|                       |          |            | FOREIGN PATENT DOCUMENTS |              |         |
|                       |          |            | JP                       | 2003-315781  | 11/2003 |
| JP                    | 8-36186  | 2/1996     | KR                       | 2003-0019080 | 3/2003  |
| JP                    | 8-338993 | 12/1996    | KR                       | 2003-0030822 | 4/2003  |
| JP                    | 11-95221 | 4/1999     | TW                       | 591278       | 6/2004  |

FIG. 1  
(PRIOR ART)

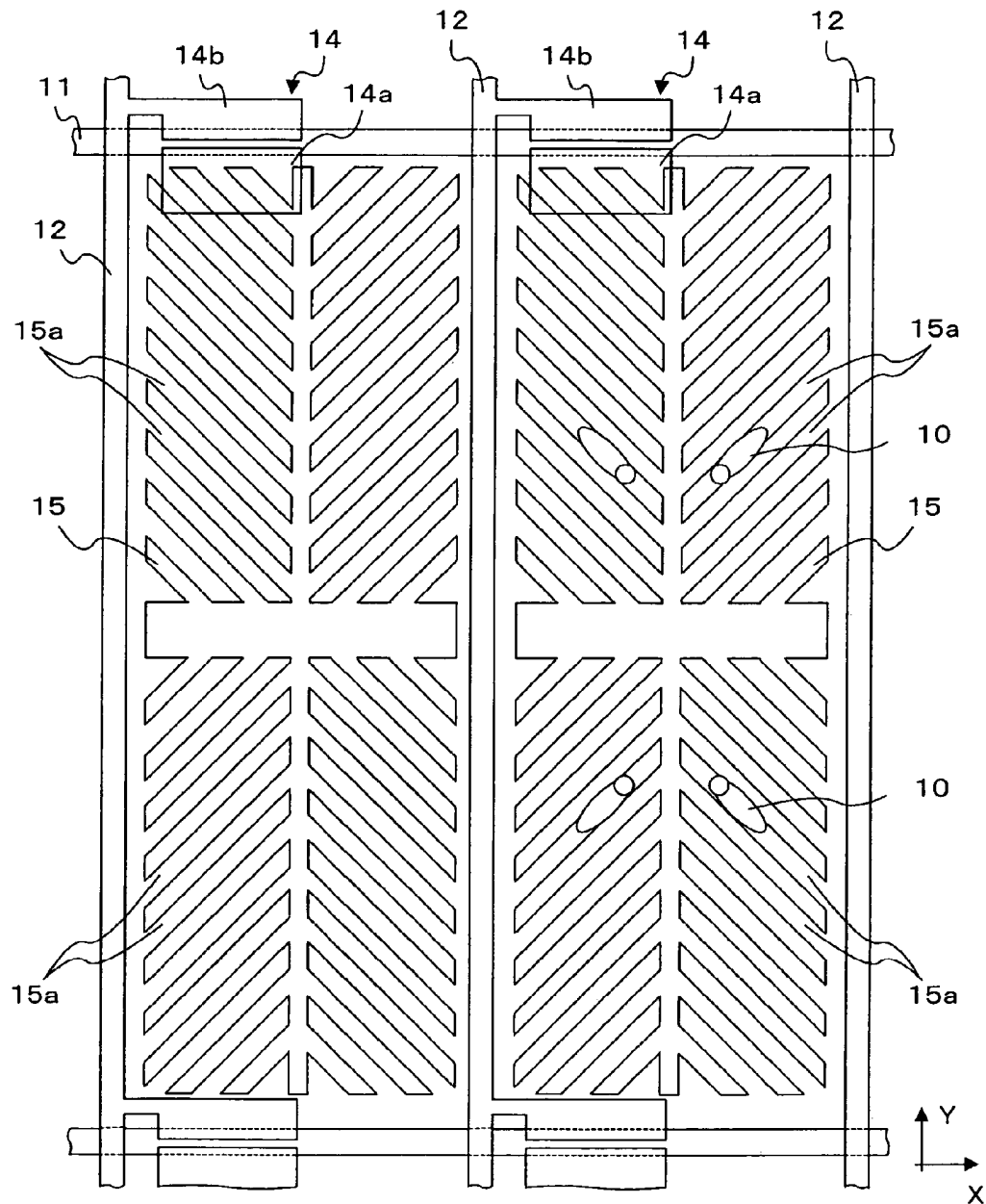


FIG. 2  
(PRIOR ART)

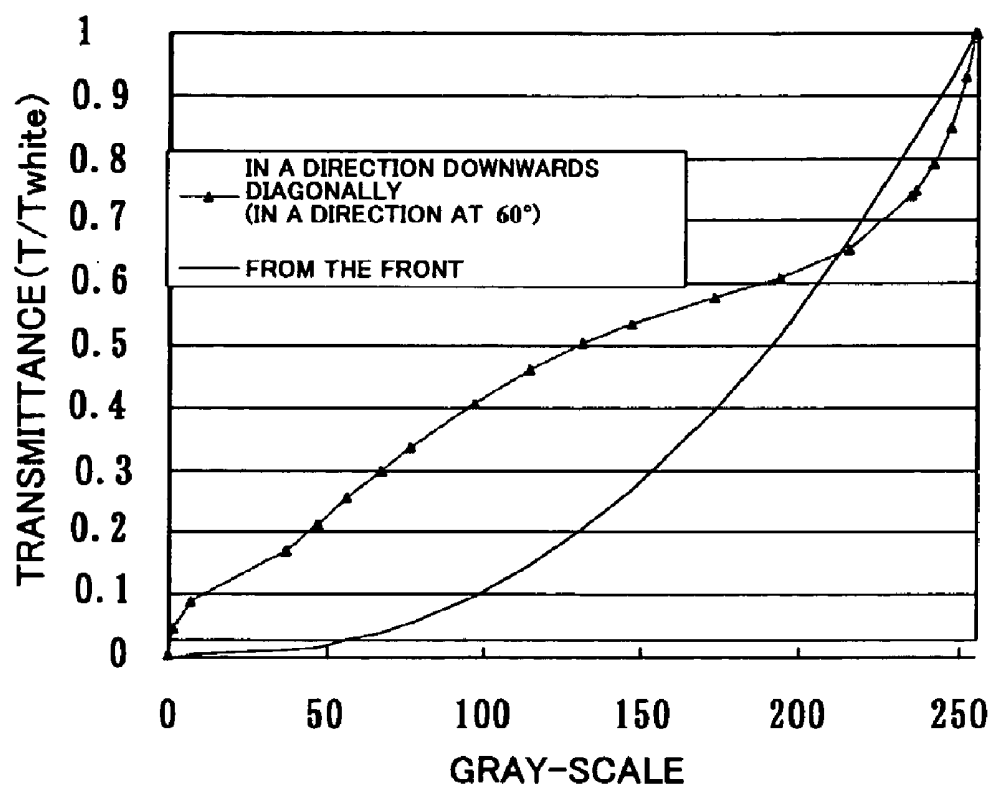


FIG. 3

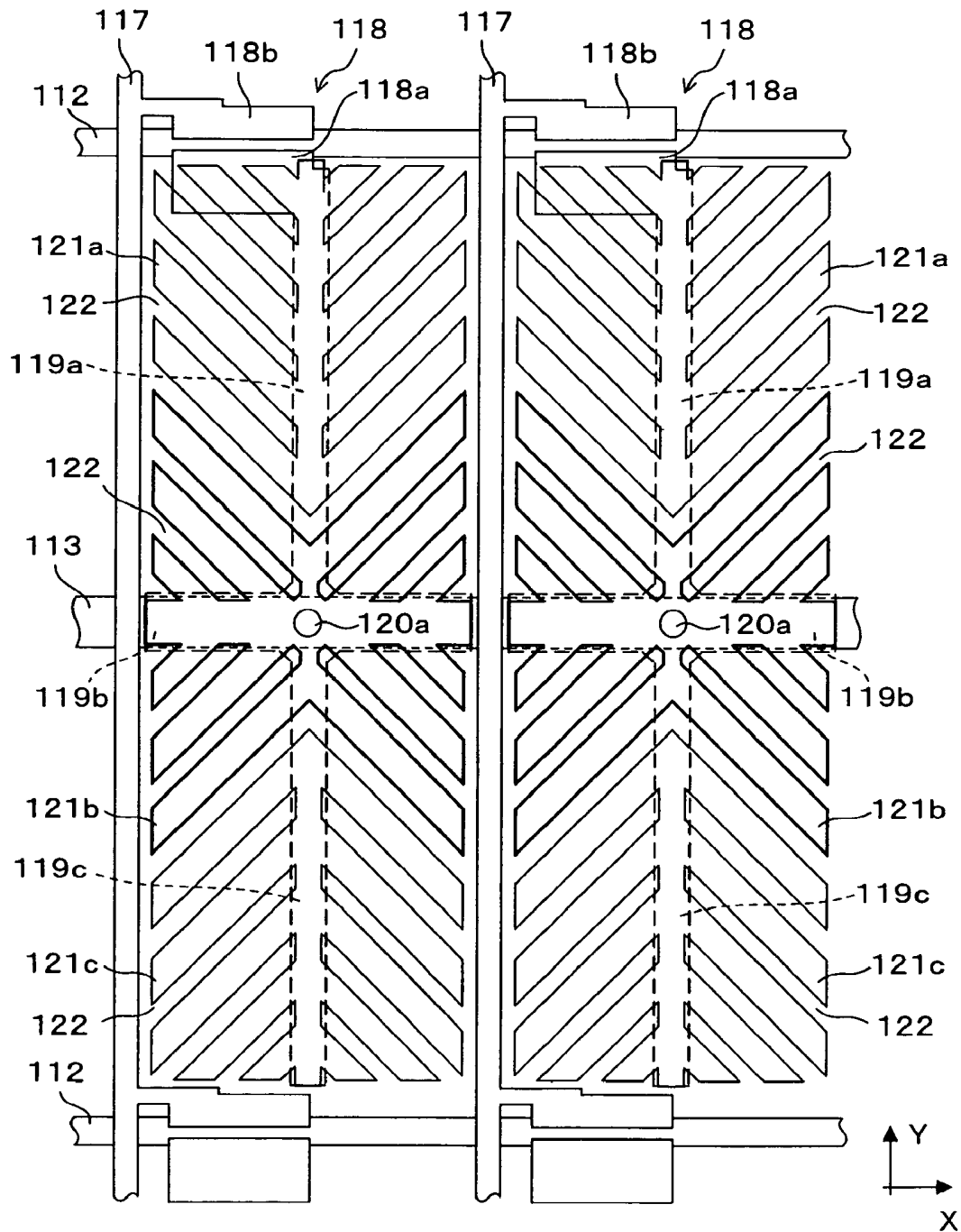


FIG. 4

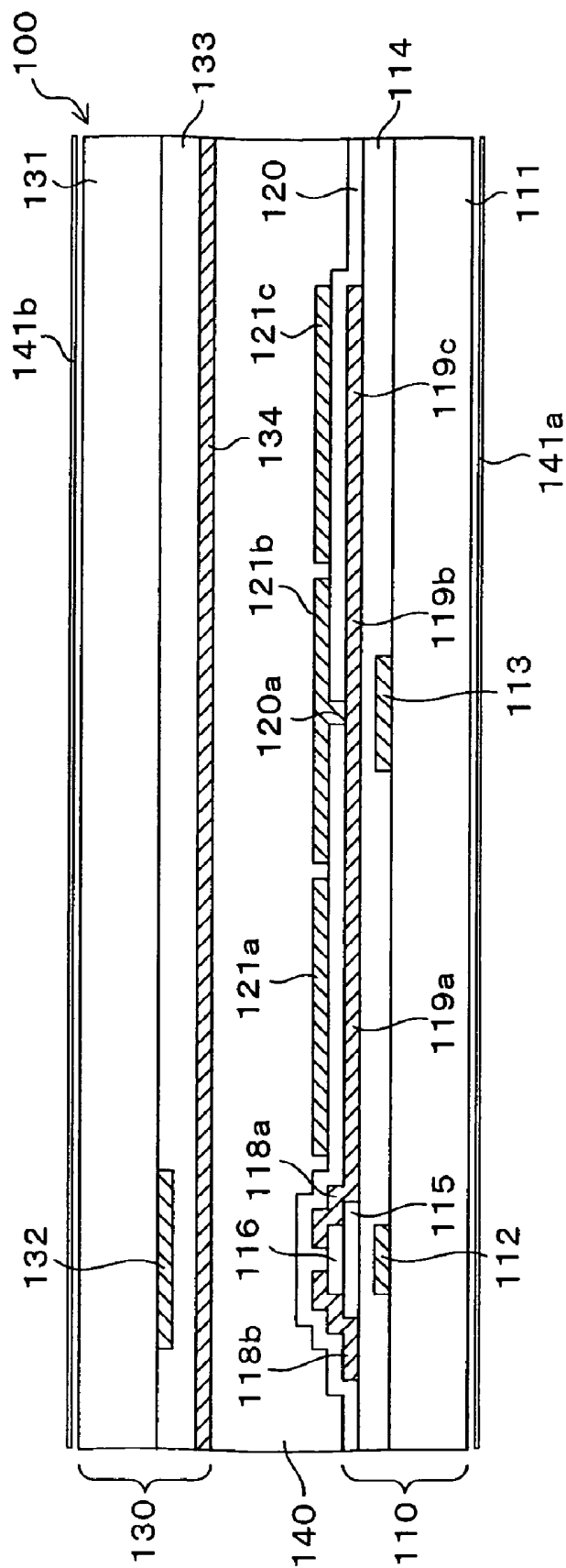


FIG. 5

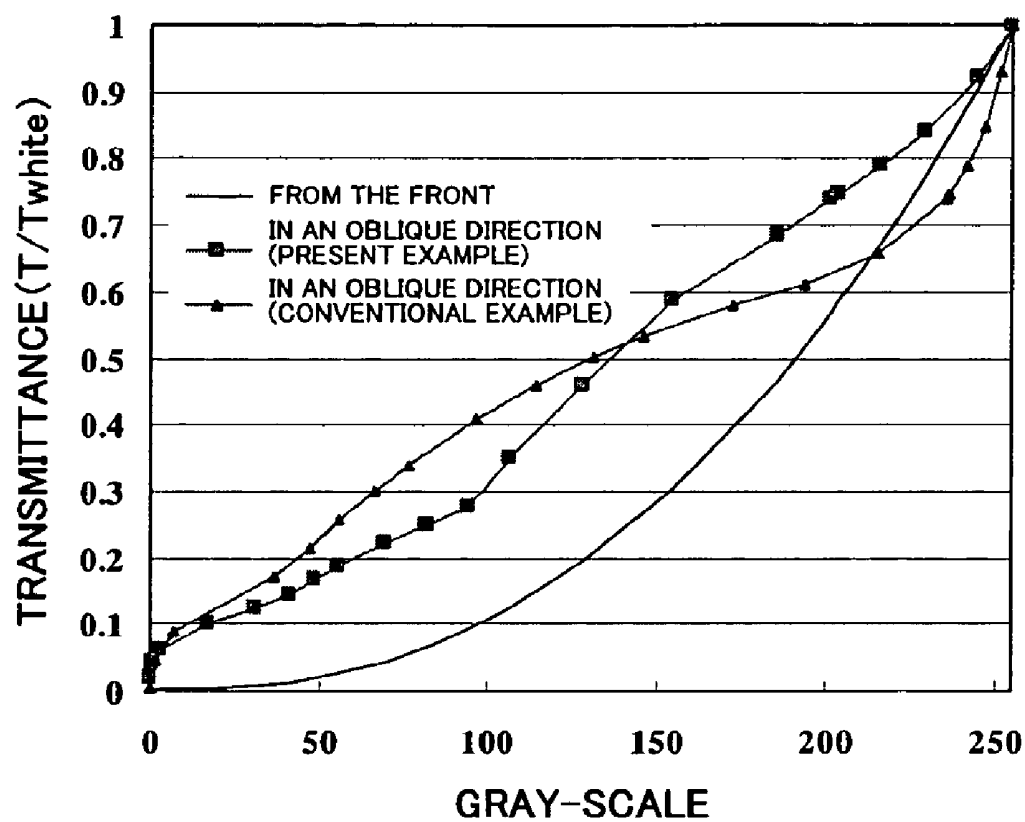


FIG. 6

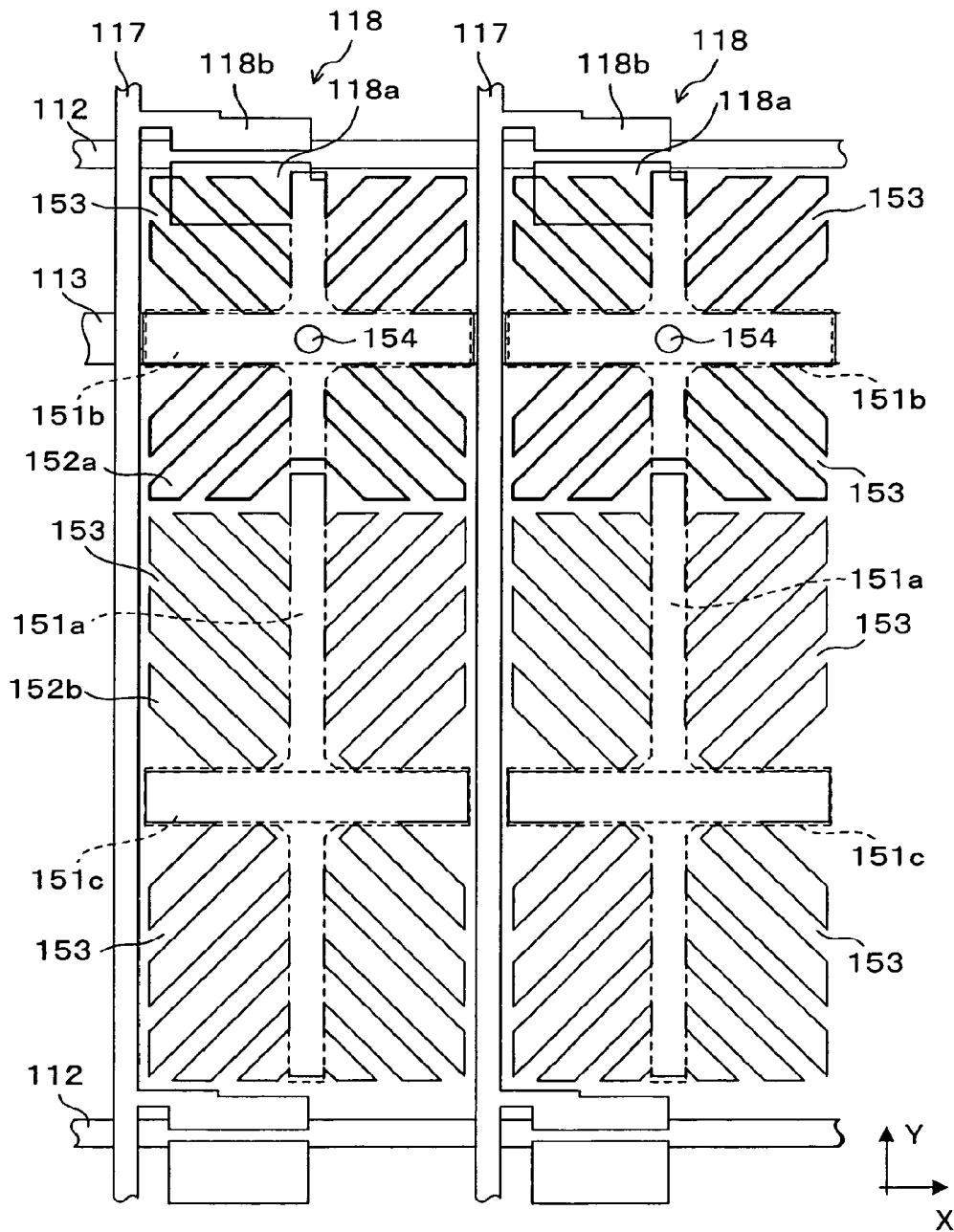


FIG. 7

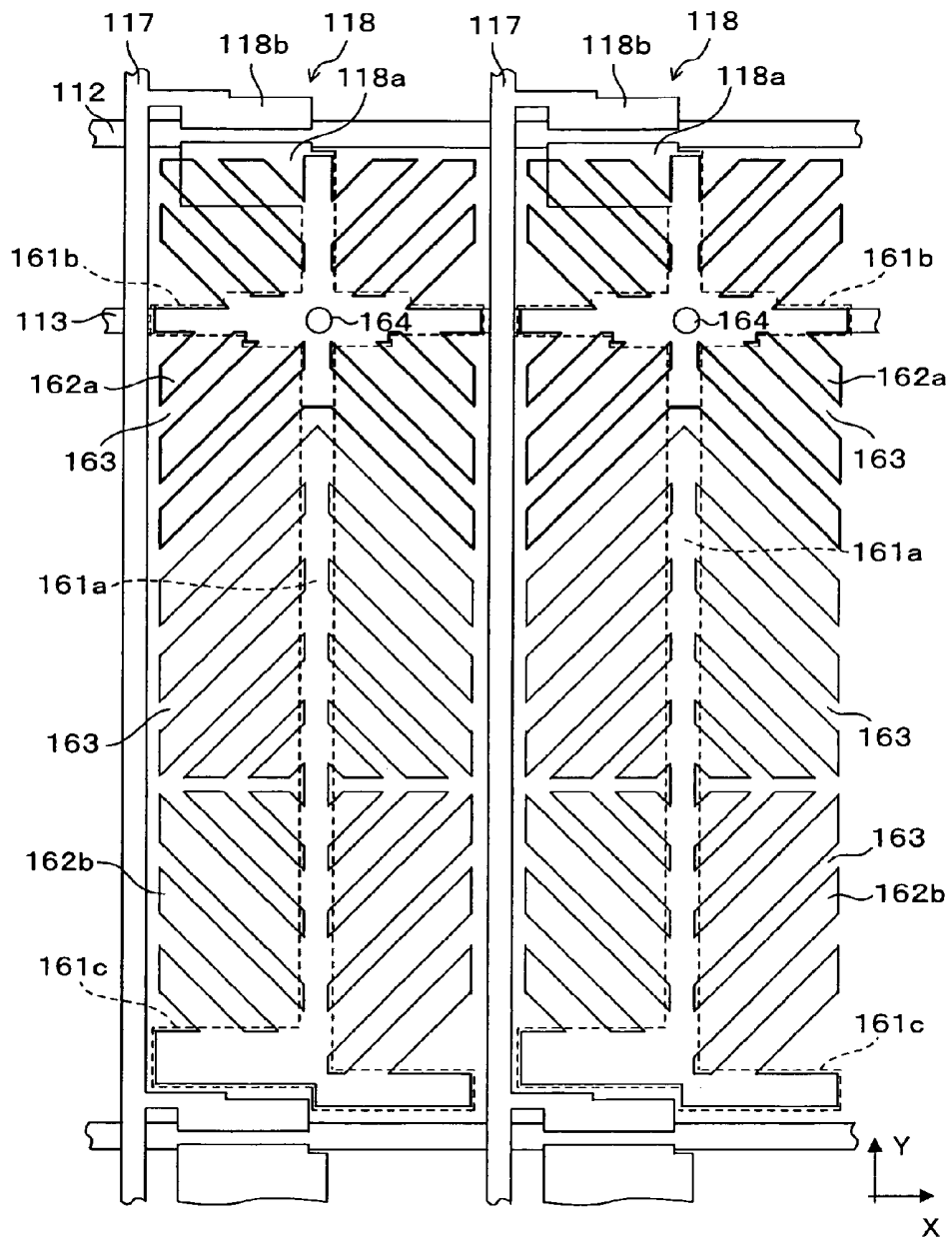


FIG. 8

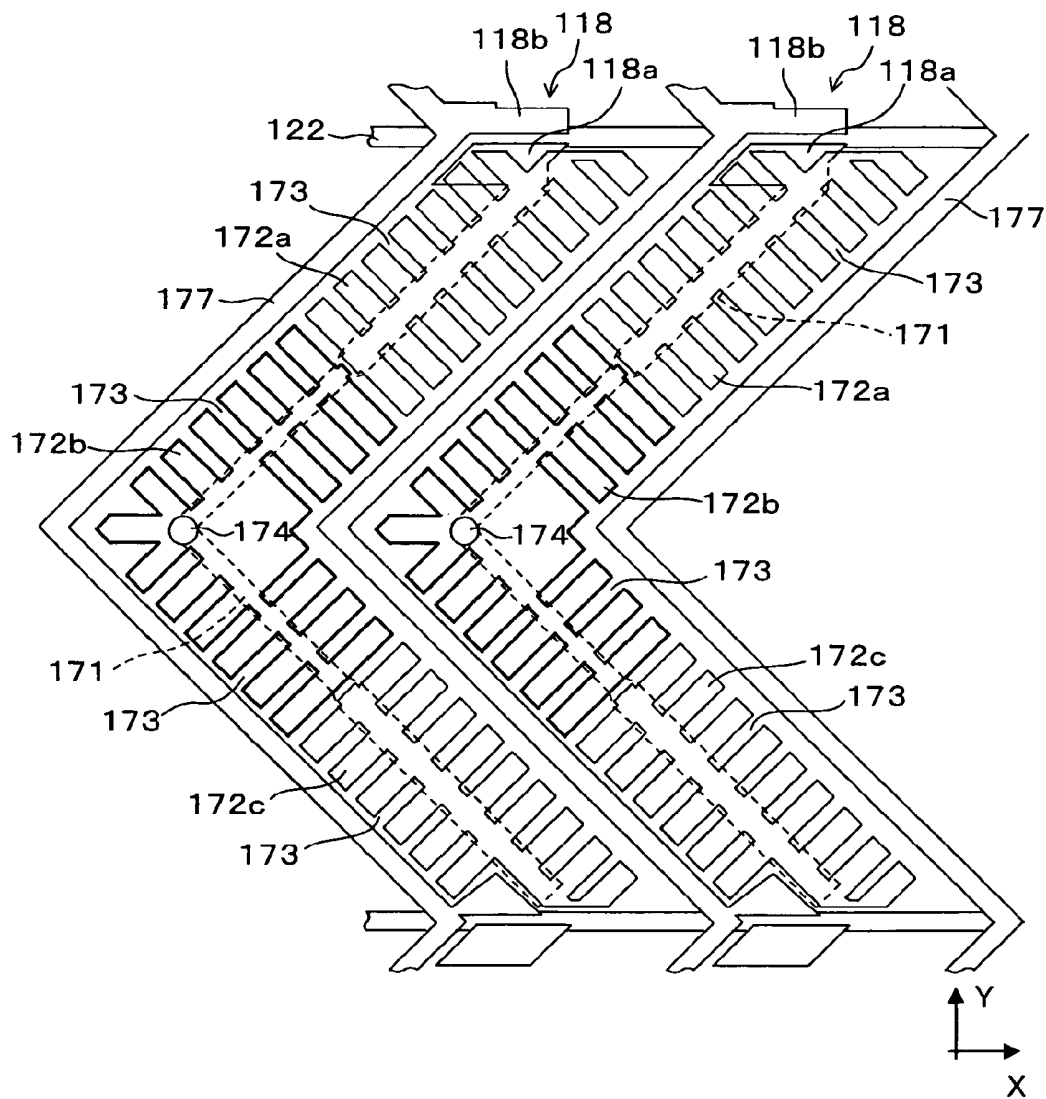


FIG. 9

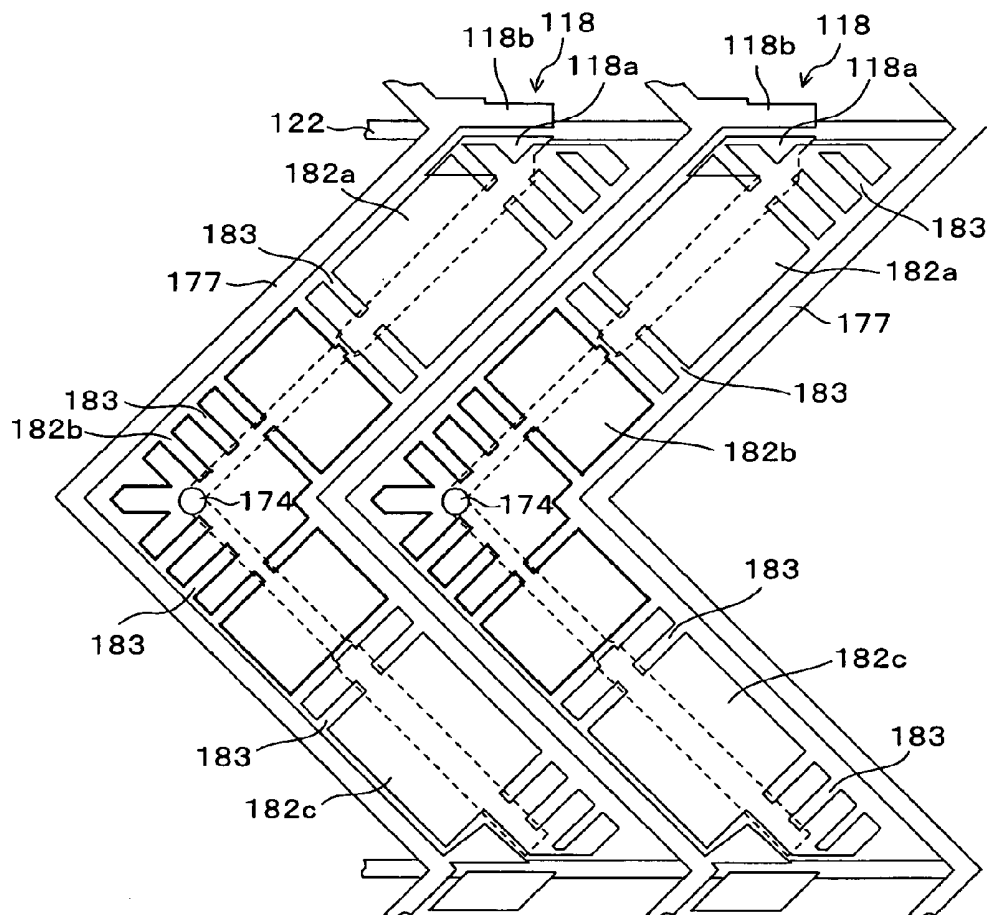


FIG. 10

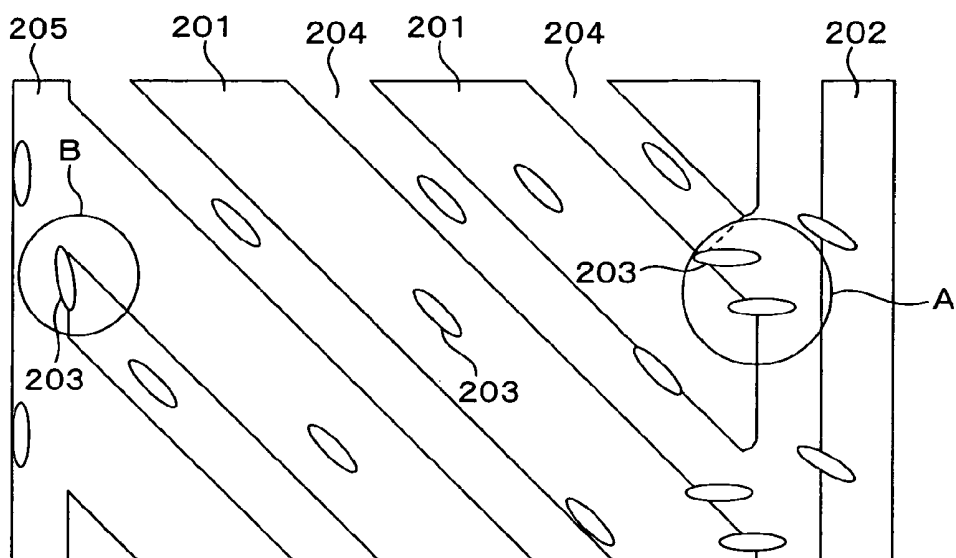


FIG. 11

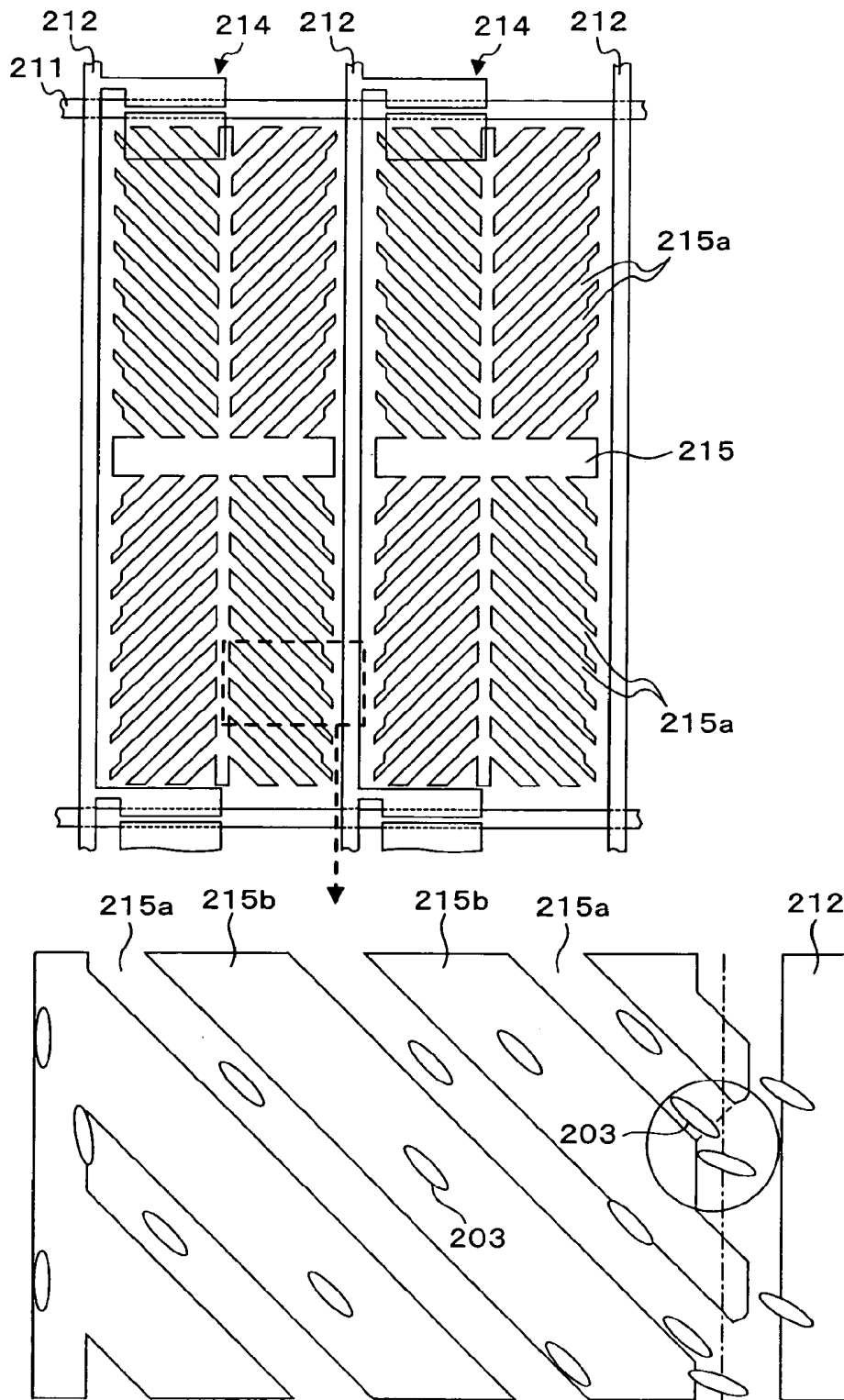


FIG. 12

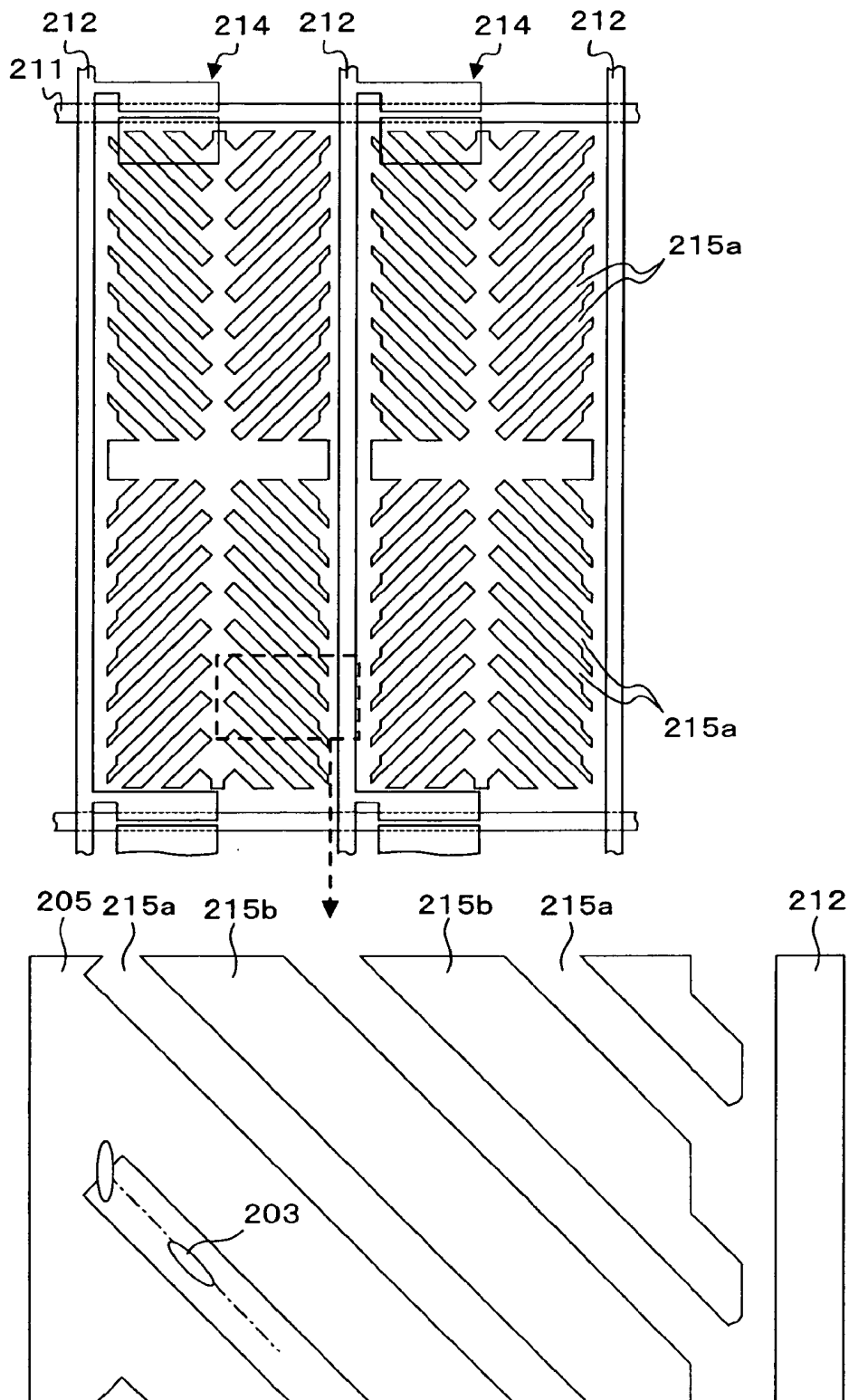


FIG. 13

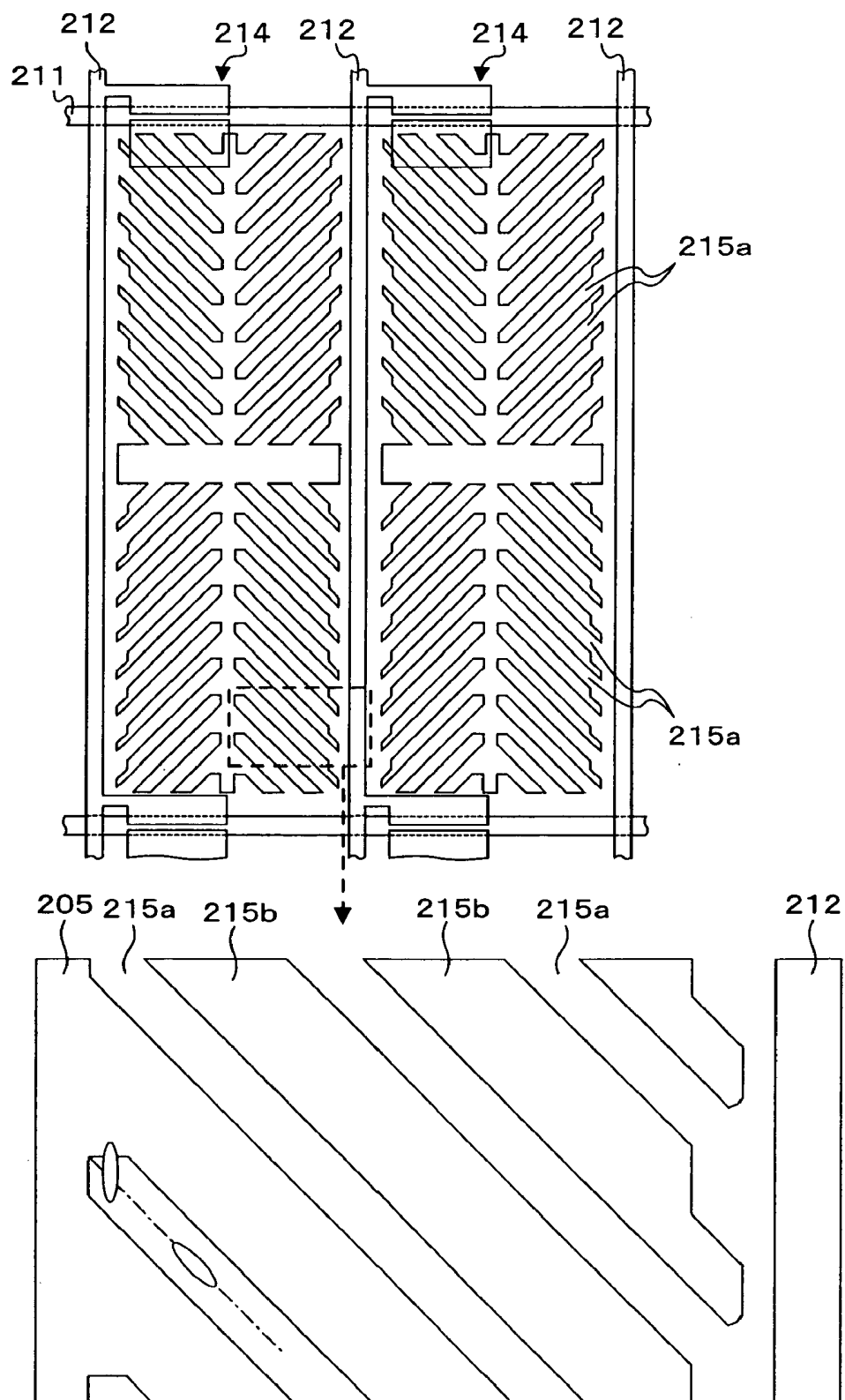


FIG. 14

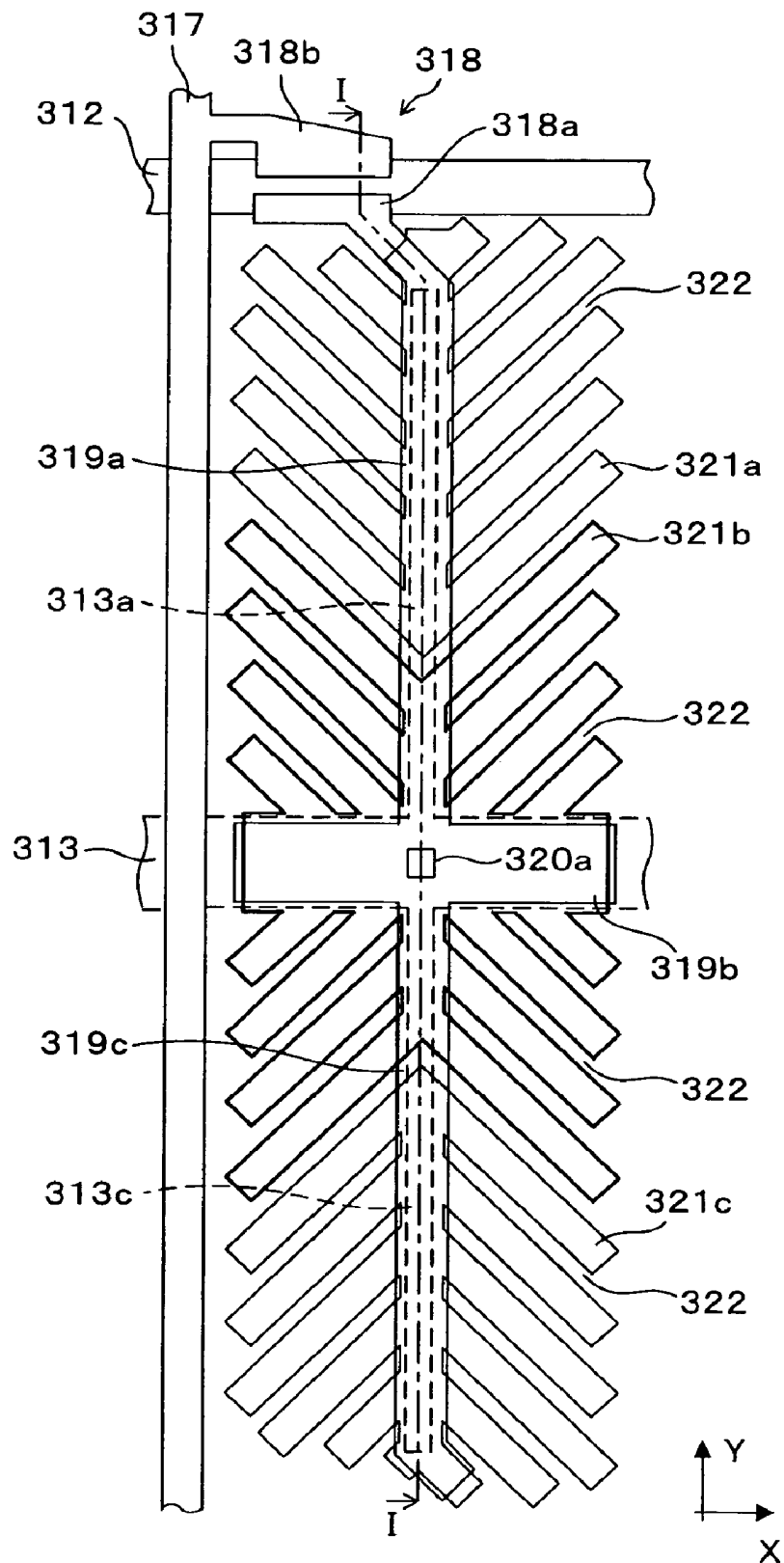




FIG. 16

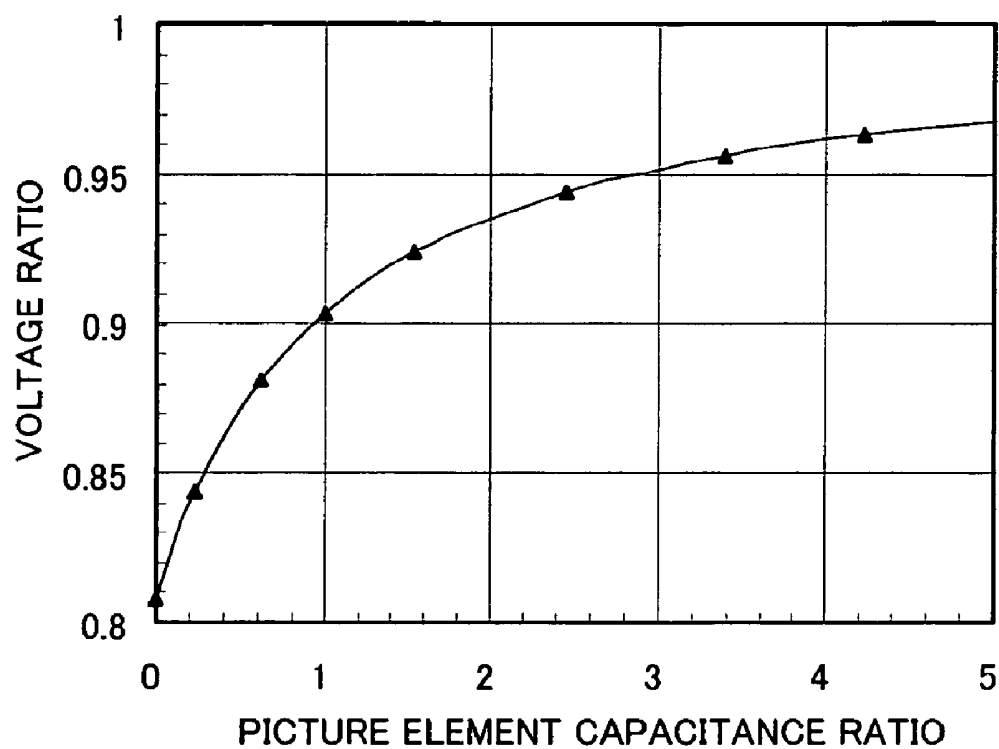


FIG. 17

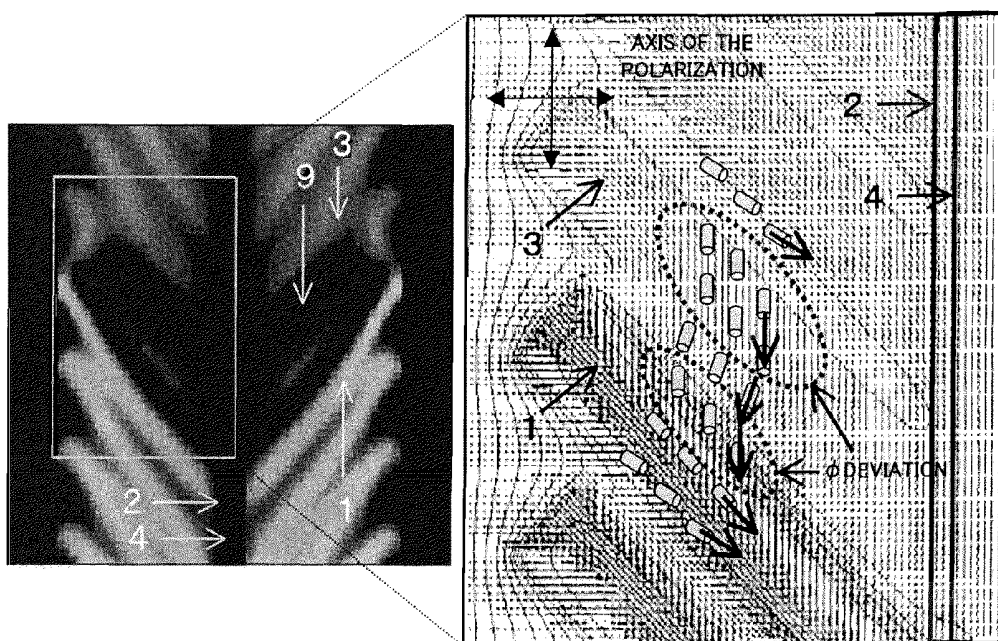




FIG. 19

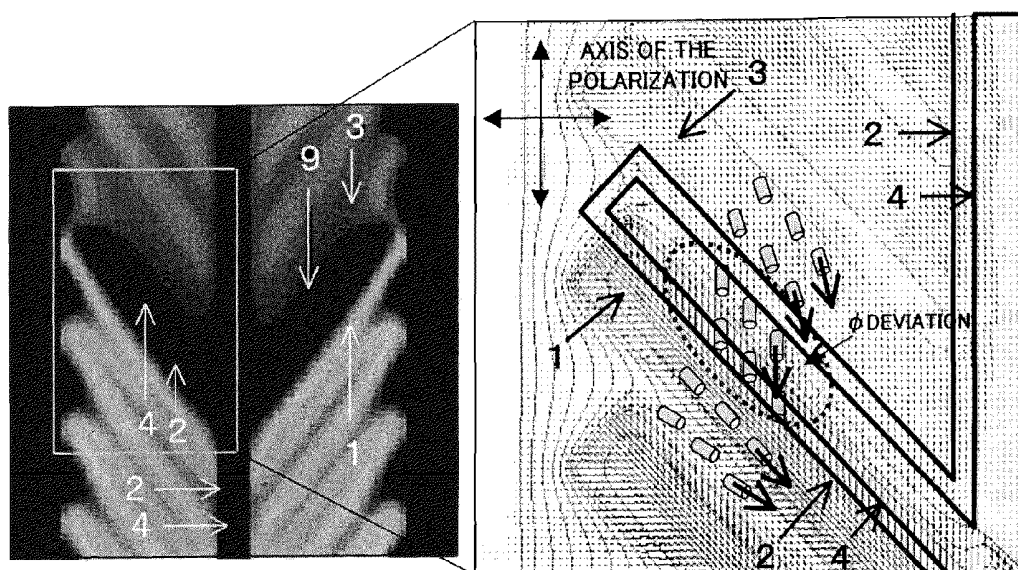


FIG. 20

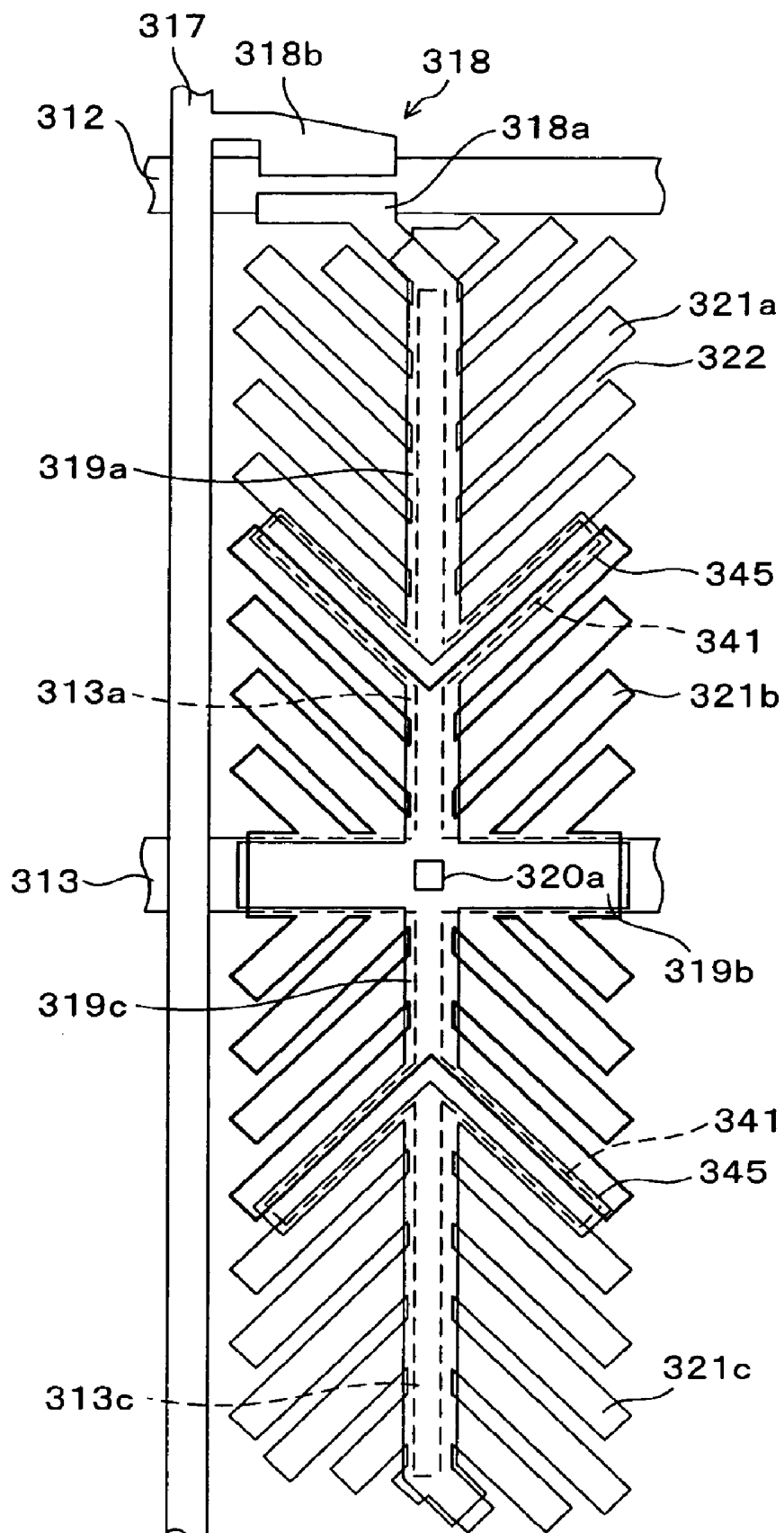


FIG. 21

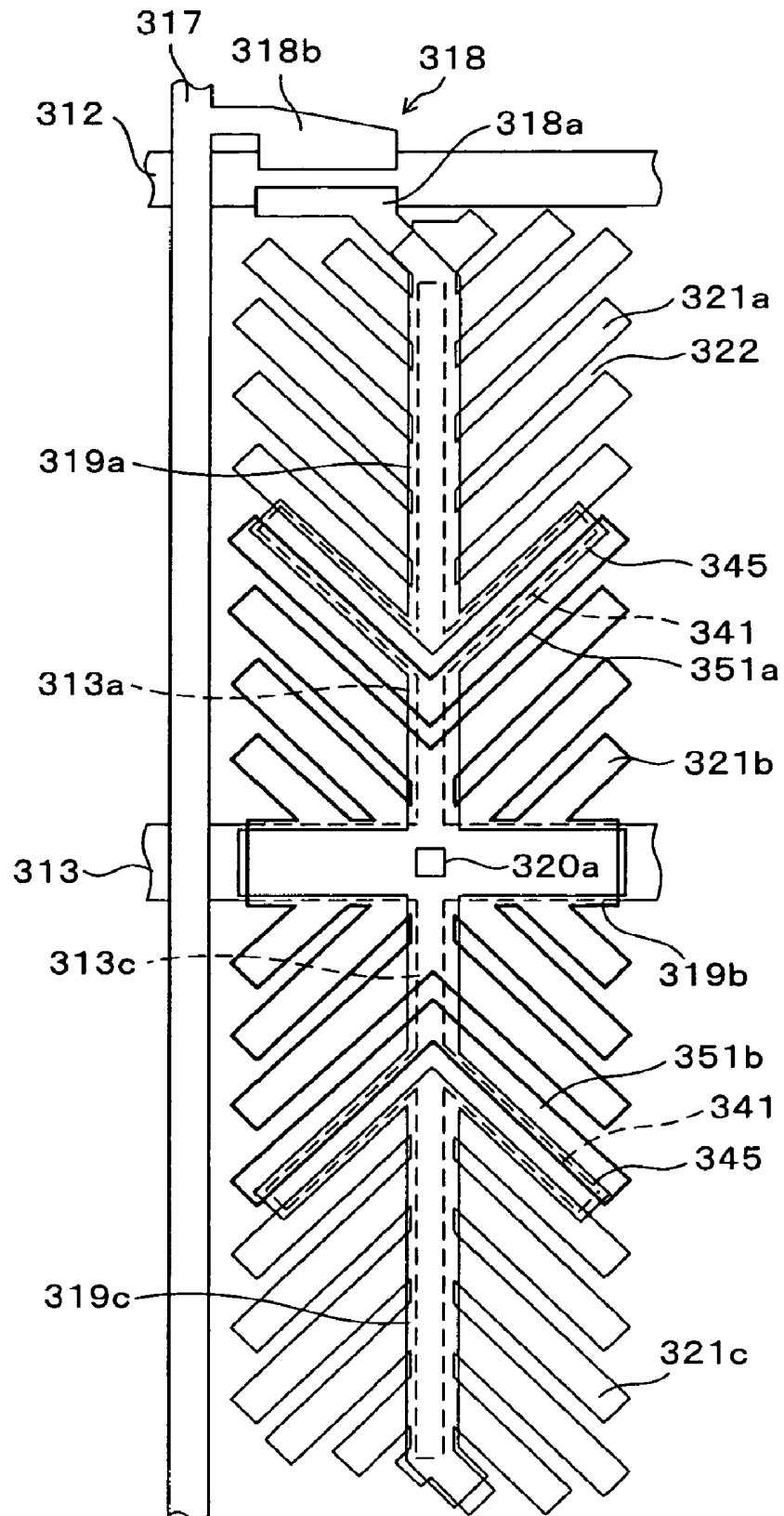


FIG. 22

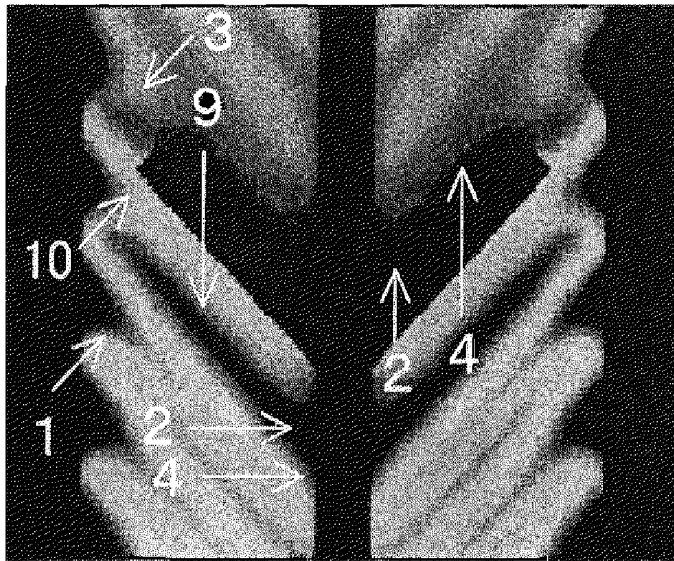


FIG. 23A

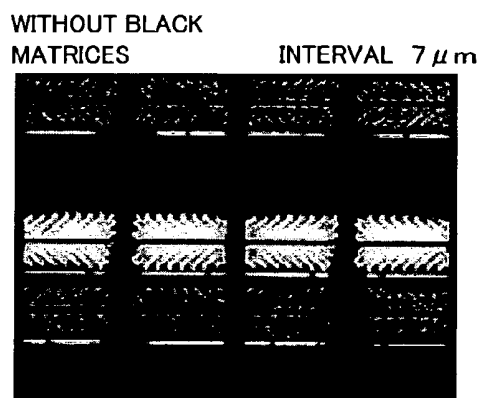


FIG. 23B

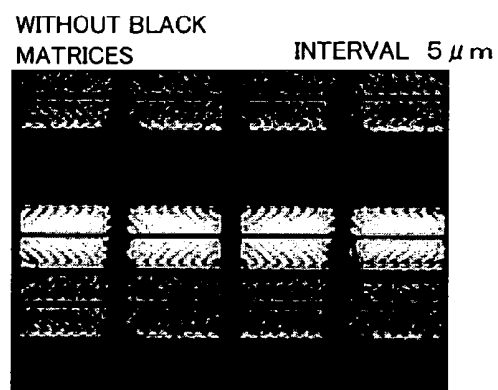


FIG. 24A

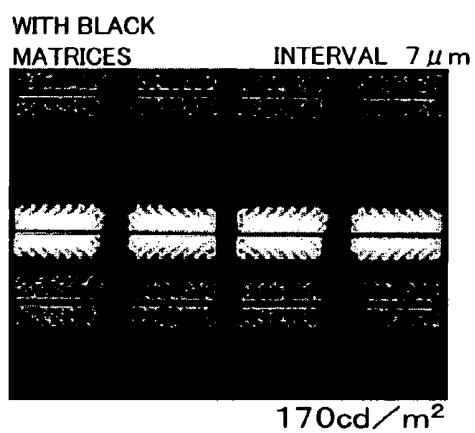


FIG. 24B

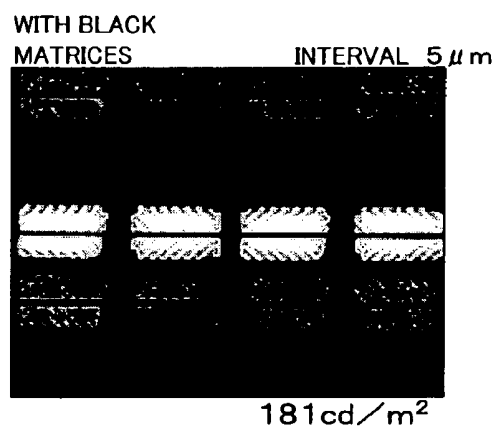


FIG. 25A

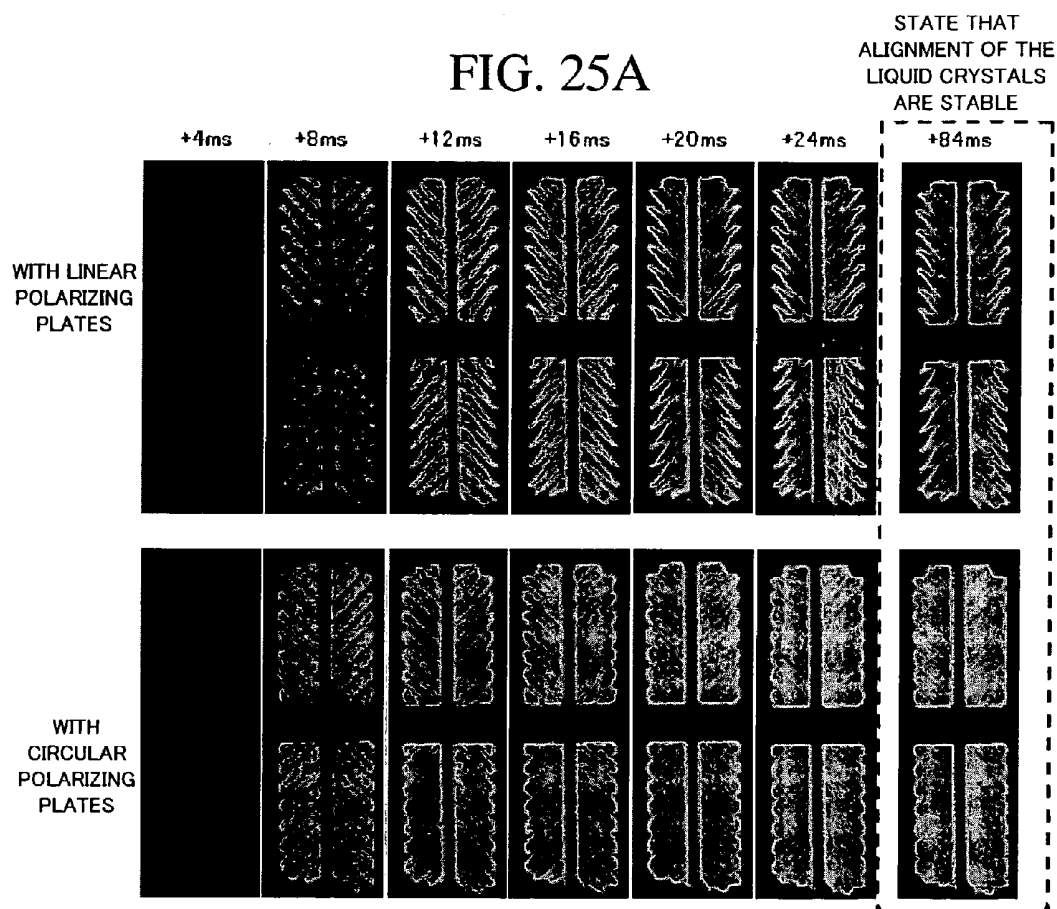


FIG. 25B

FIG. 26

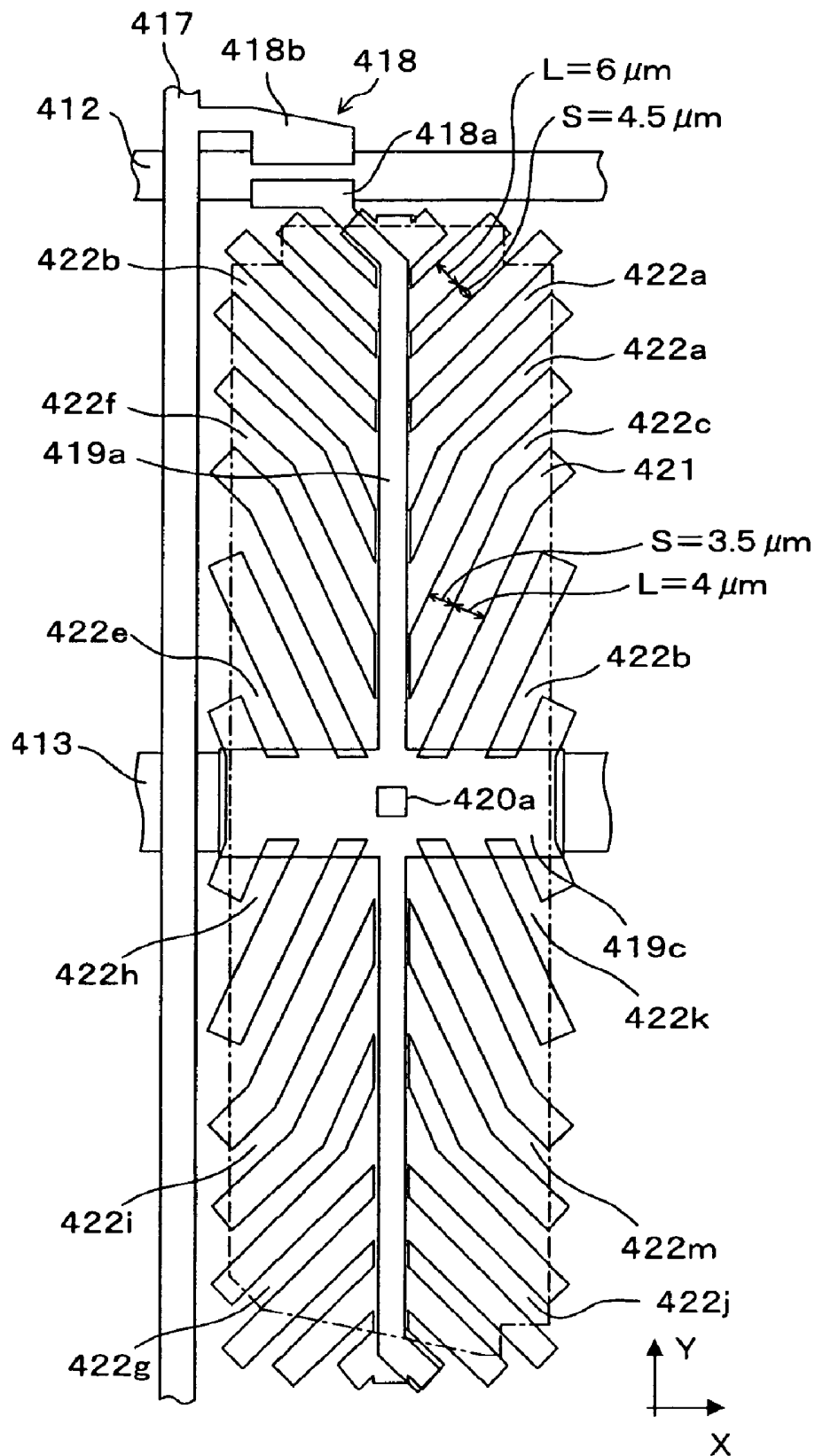


FIG. 27

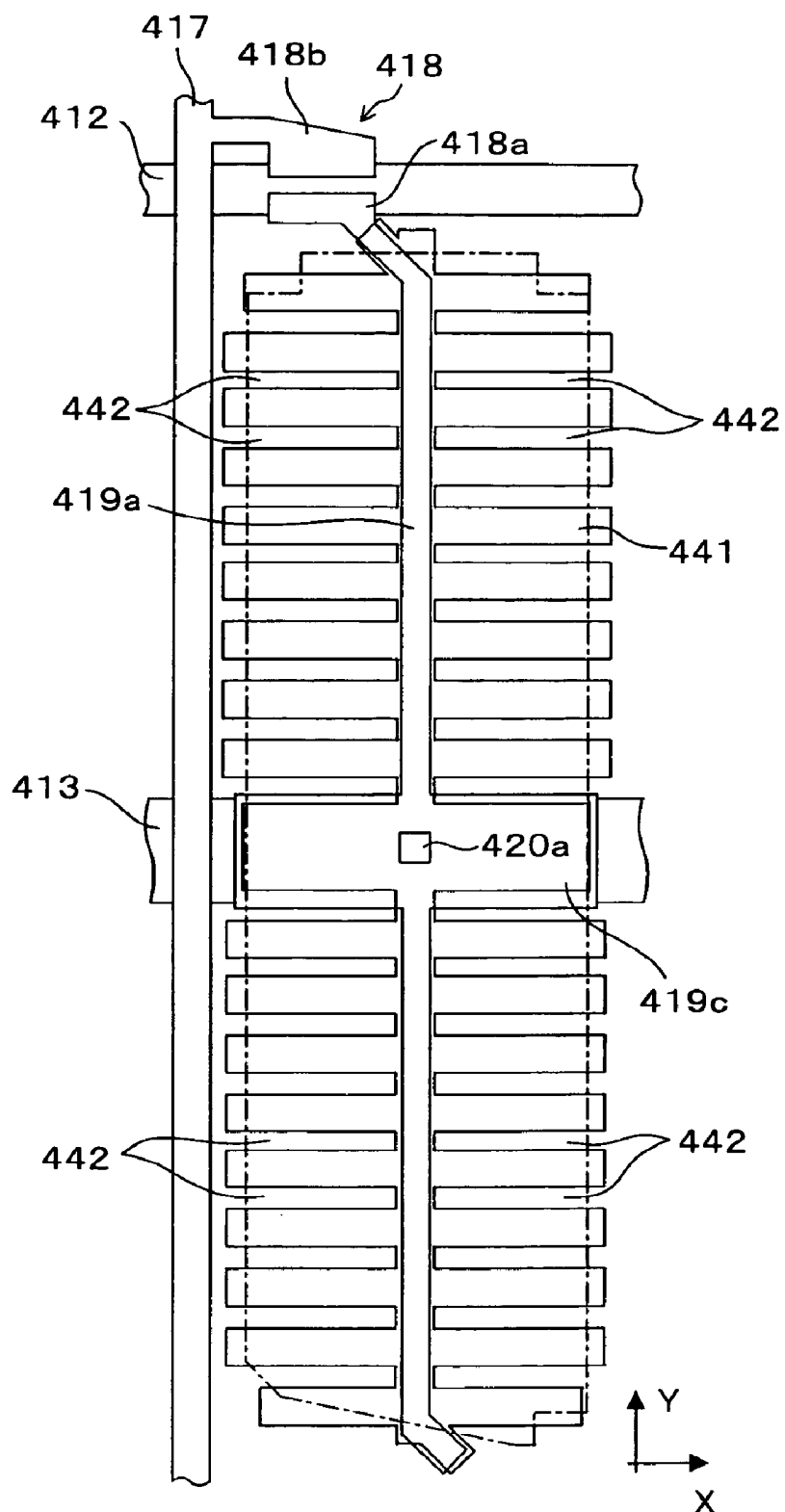


FIG. 28

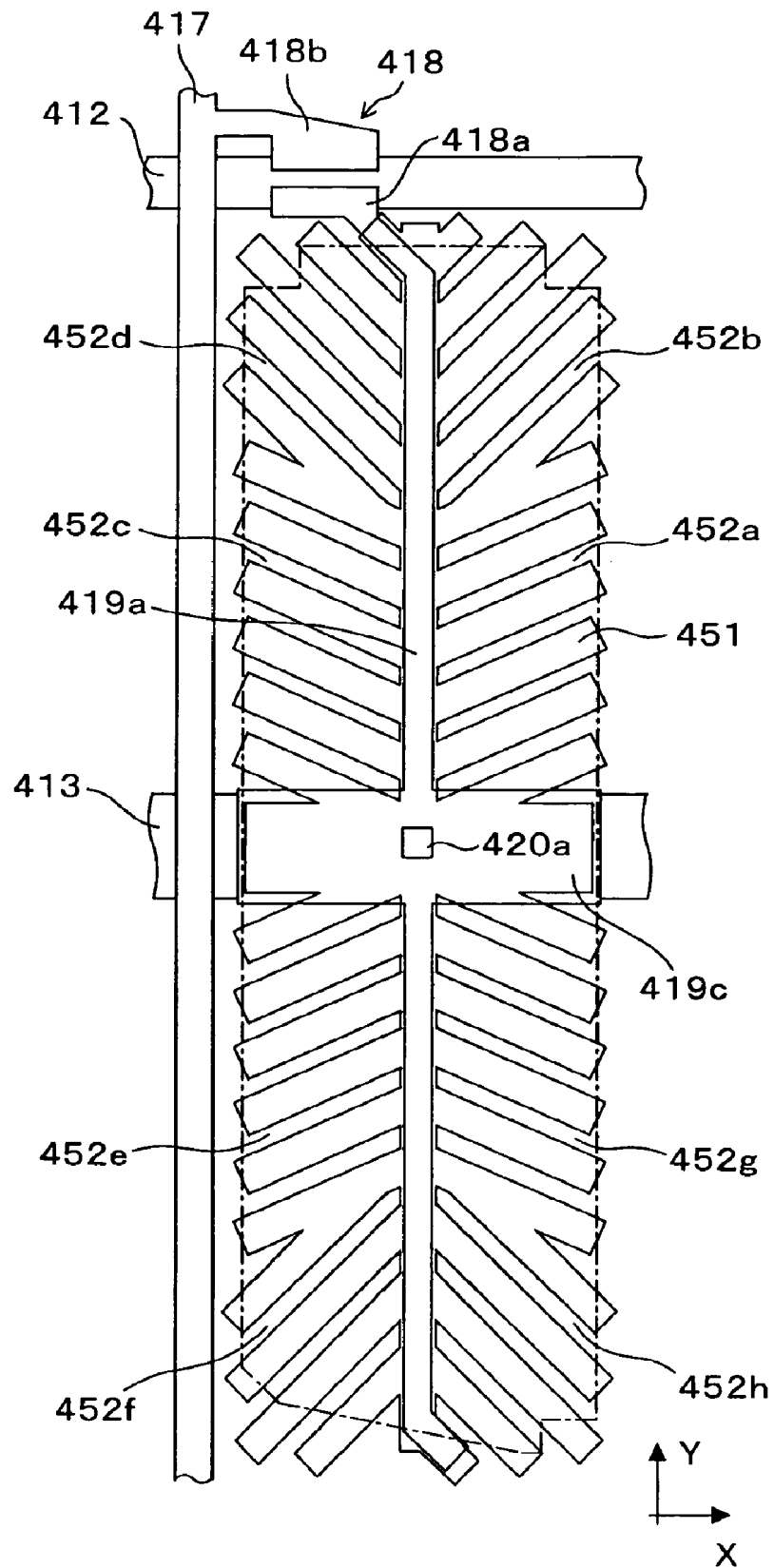


FIG. 29

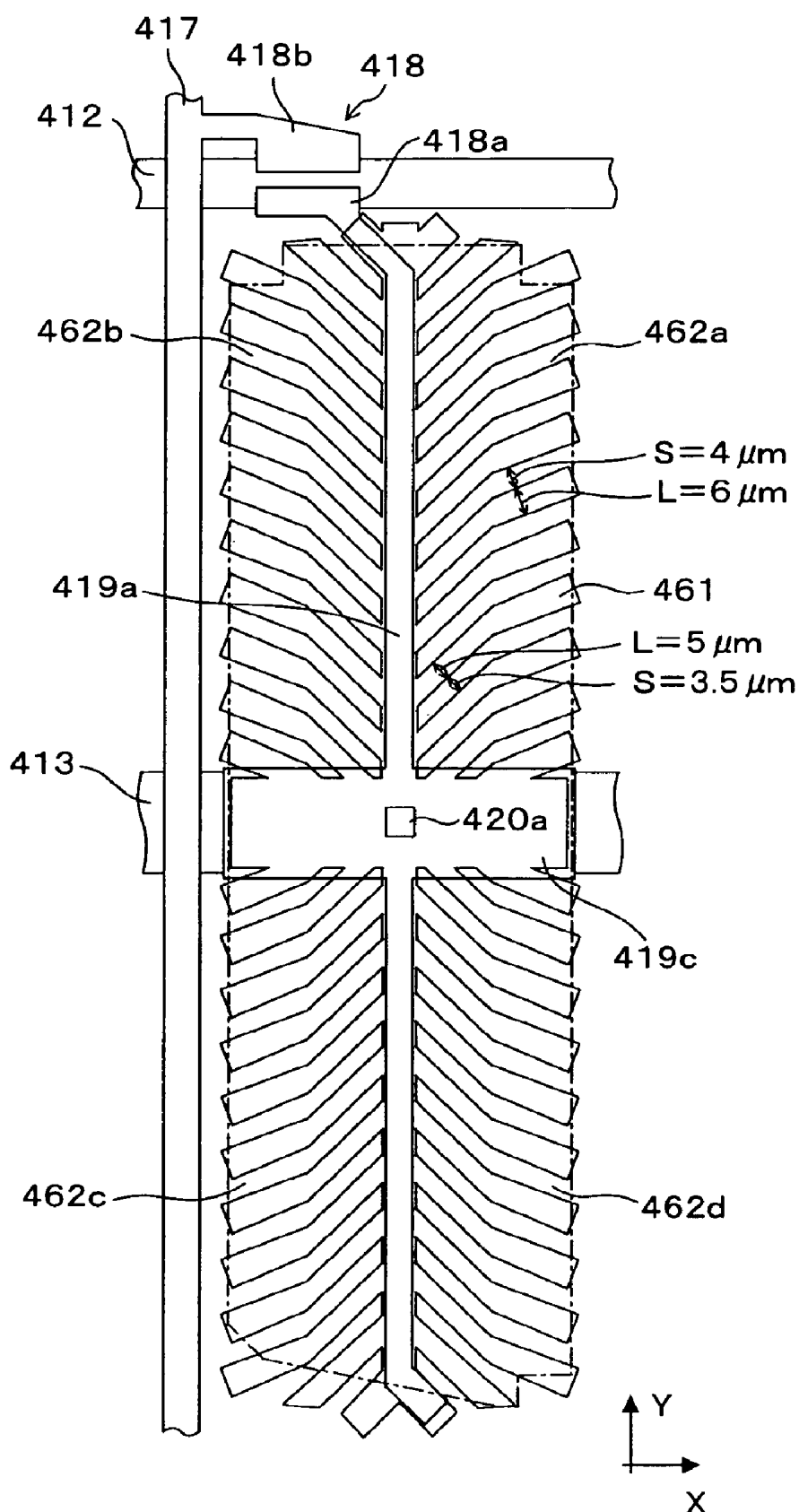


FIG. 30

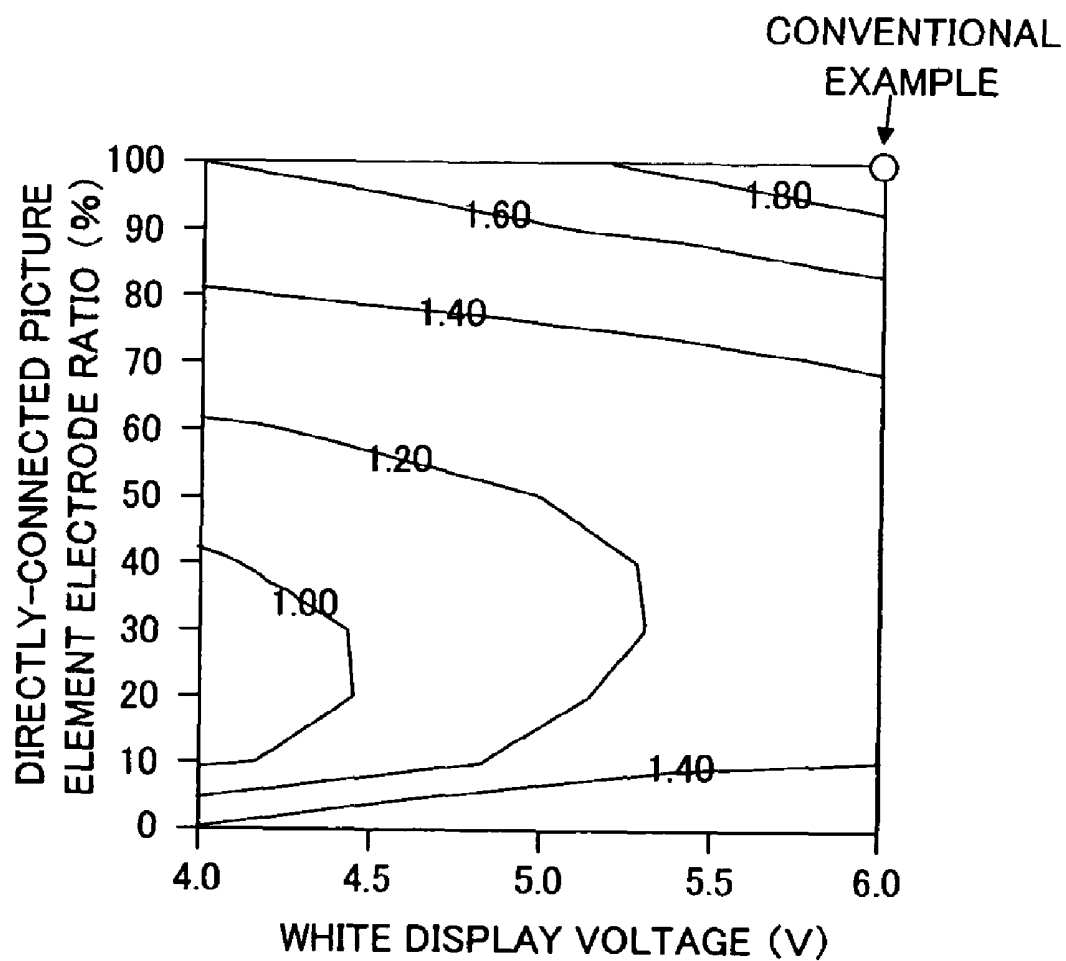


FIG. 31

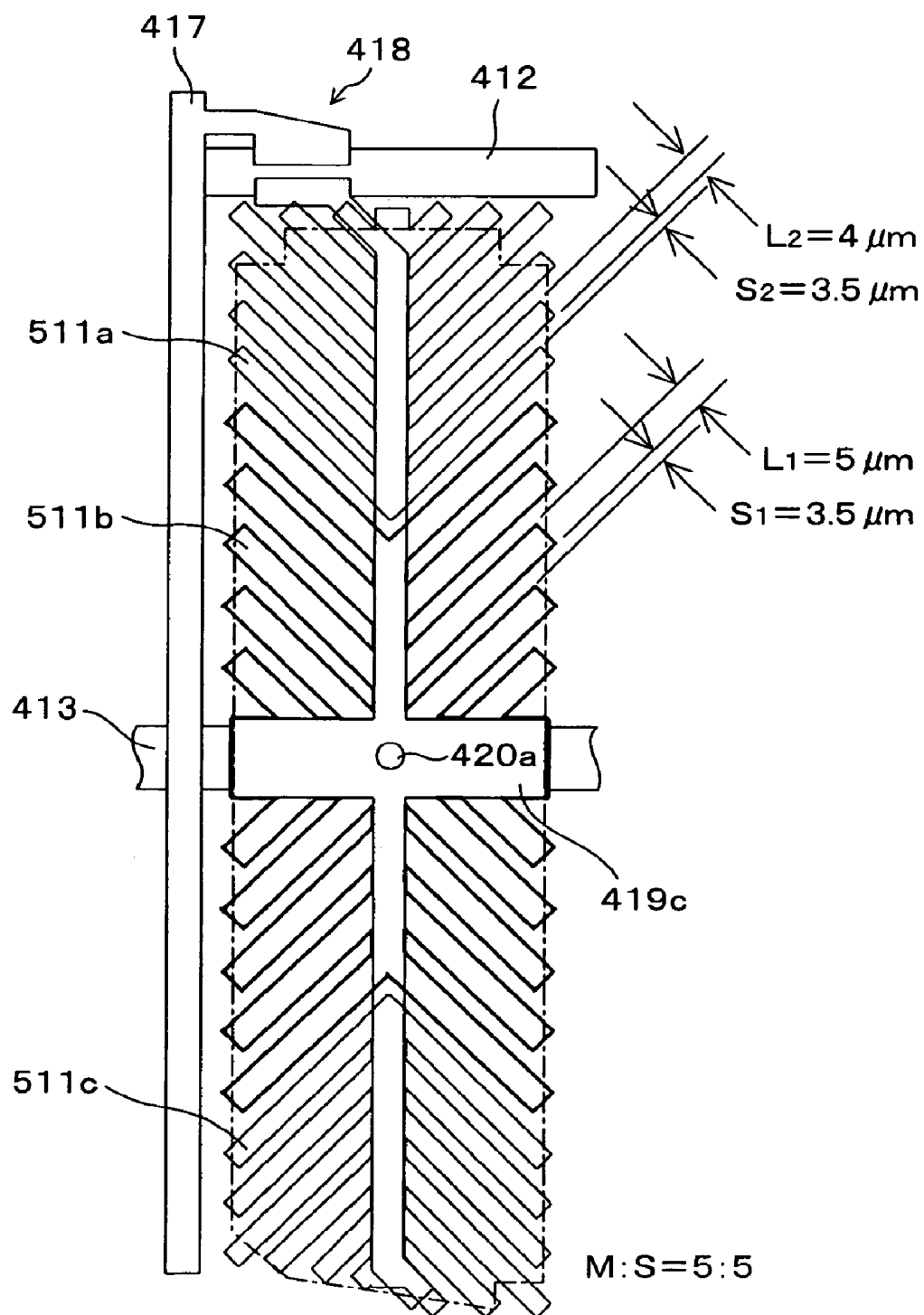


FIG. 32

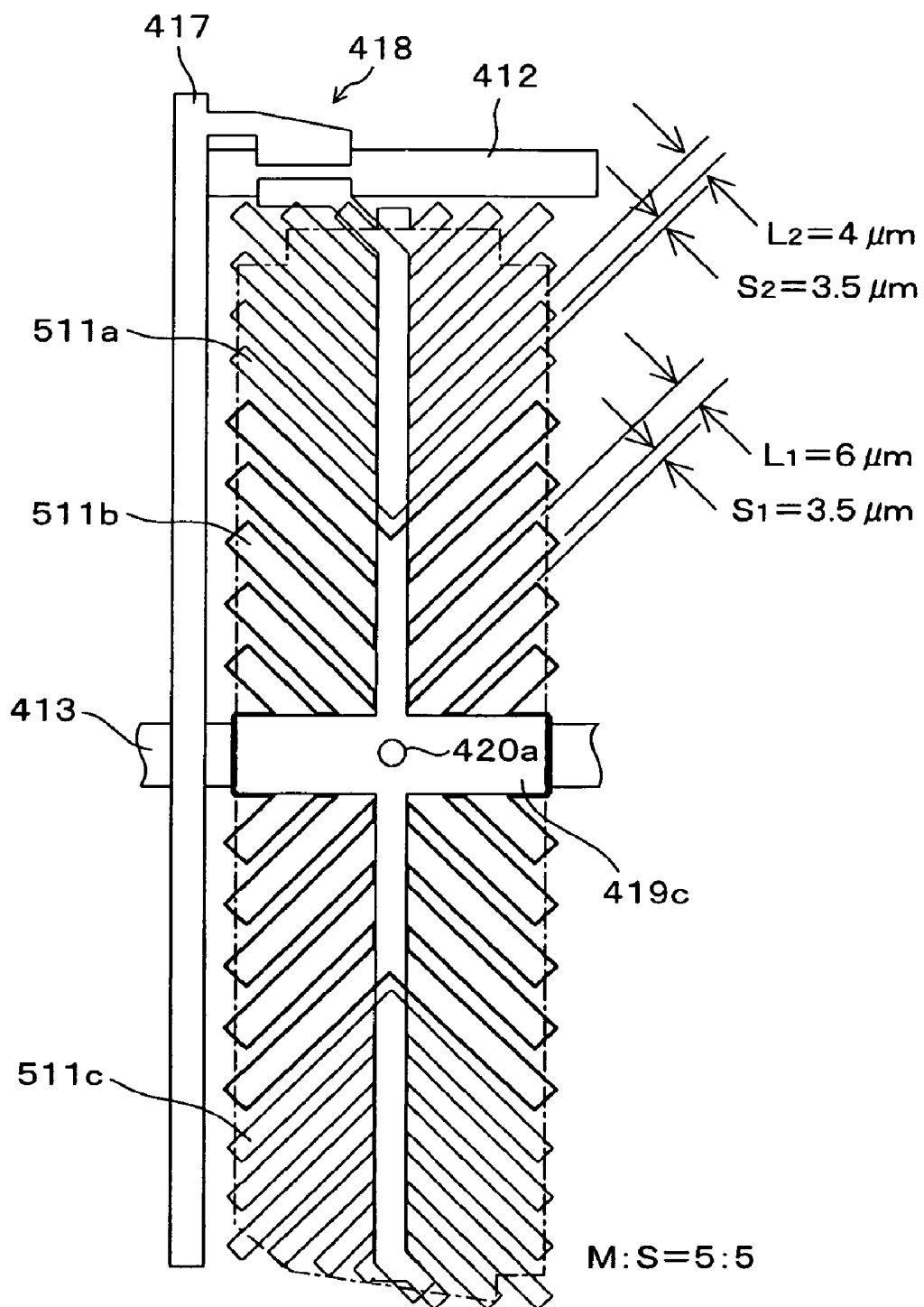


FIG. 33

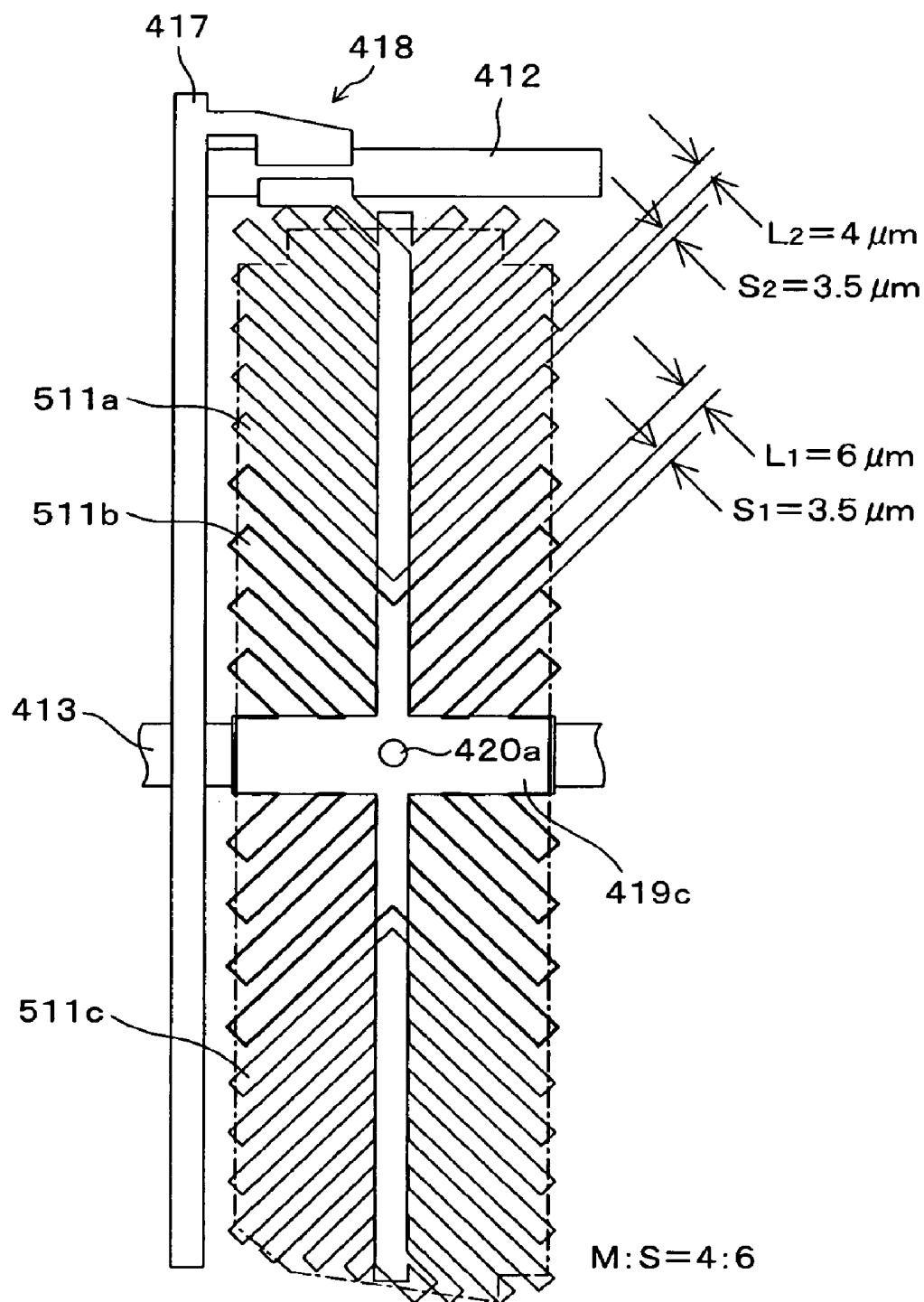
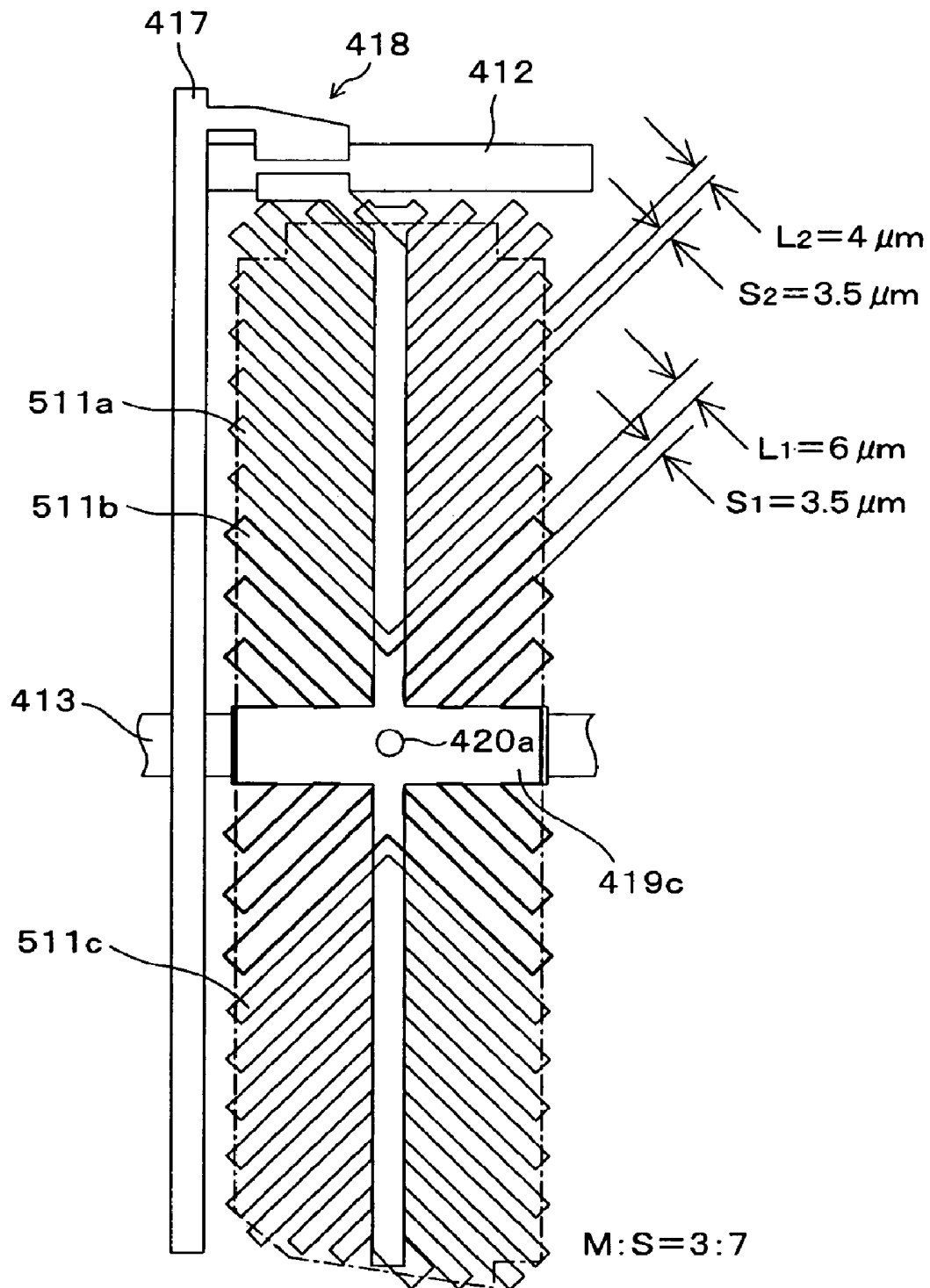


FIG. 34



## LIQUID CRYSTAL DISPLAY DEVICE

## CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a divisional of application Ser. No. 12/723,977, which is a divisional of application Ser. No. 11/104,309, filed Apr. 12, 2005, now U.S. Pat. No. 7,710,523, which claims priority of Japanese Patent Application No. 2005-001356, filed on Jan. 6, 2005, the contents being incorporated herein by reference.

## BACKGROUND OF THE INVENTION

## 1. Field of the Invention

The present invention relates to a MVA (Multi-domain Vertical Alignment) mode liquid crystal display device, and particularly to a liquid crystal display device in which a polymer for determining a direction in which liquid crystal molecules tilt while voltage is being applied is formed in a liquid crystal layer thereof.

## 2. Description of the Prior Art

In general, a liquid crystal display device is constituted of: a liquid crystal panel which is fabricated to contain liquid crystal between two substrates thereof; and polarizing plates which are arranged respectively in the two sides of the liquid crystal panel. A picture element electrode is formed in each of picture elements in one substrate of the liquid crystal panel. A common electrode used commonly for the picture elements is formed in the other substrate of the liquid crystal panel. When voltage is applied between the picture element electrode and the common electrode, alignment directions of liquid crystal molecules change depending on the voltage. As a result, this changes an amount of light which passes the liquid crystal panel and the polarizing plates arranged respectively on the two sides of the liquid crystal panel. If applied voltage were controlled for each of the picture elements, a desired image can be displayed on the liquid crystal display device.

With regard to a TN (Twisted Nematic) mode liquid crystal display device which has been heretofore used widely, liquid crystal with positive dielectric anisotropy is used, and liquid crystal molecule is twisted and aligned between the two substrates. However, the TN mode liquid crystal display device has a disadvantage of having insufficient viewing angle characteristics. In other words, with regard to the TN mode liquid crystal display device, tone and contrast are extremely deteriorated when the liquid crystal panel is viewed in an oblique direction. Accordingly, the contrast is reversed in extreme cases.

An IPS (In-Plane Switching) mode liquid crystal display device and a MVA (Multi-domain Vertical Alignment) mode liquid crystal display device have been known as liquid crystal display devices having good viewing angle characteristics. With regard to the IPS mode liquid crystal display device, picture element electrodes shaped like a line and common electrodes shaped like a line are arranged alternately in one of the two substrates. If voltage were applied between one of the picture element electrodes and neighboring one of the common electrodes, the orientations respectively of the liquid crystal molecules change in a plane parallel with a surface of the substrate depending on the voltage.

Although, however, the IPS mode liquid crystal display device is good at viewing angle characteristics, the orientations respectively of the liquid crystal molecules above the picture element electrode and the common electrode cannot be controlled since voltage is applied in a direction which is parallel with the substrate. This brings about a disadvantage

that the IPS mode liquid crystal display device substantially has a low aperture ratio, and that the screen of it is dark if a powerful backlight were not used.

With regard to the MVA mode liquid crystal display device, picture element electrodes are formed in one of the two substrates, and a common electrode is formed in the other of the two substrates. In addition, with regard to a generally-used MVA mode liquid crystal display device, bank-shaped protrusions made of dielectric material extending in an oblique direction are formed on the common electrode. Each of the picture element electrodes is provided with slits parallel with the protrusions.

With regard to the MVA mode liquid crystal display device, while voltage is not being applied, the liquid crystal molecules are aligned in a direction perpendicular to the substrates. When voltage is applied between each of the picture element electrodes and the corresponding common electrode, the liquid crystal molecules are aligned to tilt at an angle corresponding to the voltage. In this occasion, a plurality of domains are formed in each of the picture elements by the slits provided into the picture element electrode and by the corresponding bank-shaped protrusions. The directions in which the liquid crystal molecules tilt vary from one domain to another. If the plurality of domains were formed in any one of the picture elements while the directions in which the liquid crystal molecules tilt vary from one domain to another, good viewing angle characteristics can be obtained.

With regard to the aforementioned MVA mode liquid crystal display device, the slits and the protrusions decrease the substantial aperture ratio. Accordingly, the substantial aperture ratio of the MVA mode liquid crystal display device is lower than that of the TN mode liquid crystal display device, although the substantial aperture ratio is not so low as that of the IPS mode liquid crystal display device. For this reason, the MVA mode liquid crystal display device needs a powerful backlight. As a result, this kind of MVA mode liquid crystal display device has hardly been adopted for a notebook personal computer, which requires power consumption to be low.

Japanese Patent Laid-open Official Gazette No. 2003-149647 has disclosed a MVA mode liquid crystal display device which was developed in order to solve the aforementioned problems. FIG. 1 is a plan view showing the MVA mode liquid crystal display device. Incidentally, FIG. 1 shows two picture element regions.

A plurality of gate bus lines **11** extending in the horizontal direction (X-axis direction) and a plurality of data bus lines **12** extending in the vertical direction (Y-axis direction) are formed on one of the two substrates constituting a liquid crystal panel. An insulating film (gate insulating film) is formed in each of the rectangular areas defined by the gate bus lines **11** and the data bus lines **12**. This formation electrically isolates the gate bus lines **11** from the data bus lines **12**. Each of the rectangular areas defined by the gate bus lines **11** and the data bus lines **12** is a picture element region.

A TFT (thin film transistor) **14** and a picture element electrode **15** are formed in each of the picture element region. As shown in FIG. 1, the TFT **14** uses part of the gate bus line **11** so as to cause the part to function as a gate electrode. A semiconductor film (not illustrated) which functions as an active layer of the TFT **14** is formed above the gate electrode. A drain electrode **14a** and a source electrode **14b** are connected respectively to the two sides of this semiconductor film in the Y-axis direction. The source electrode **14b** of the TFT **14** is electrically connected to the data bus line **12**, and the drain electrode **14a** is electrically connected to the picture element electrode **15**.

In this patent application, out of the two electrodes connected to the semiconductor film which functions as the active layer of the TFT, one electrode to be connected to the data bus line is termed as a source electrode, and the other electrode to be connected to the picture element electrode is

termed as a drain electrode. The picture element electrode **15** is formed of a transparent conductive material such as ITO (Indium-Tin Oxide). Slits **15a** are formed in this picture element electrode **15** in order to cause liquid crystal molecules to be aligned in one of four directions when voltage is applied. In other words, the picture element electrode **15** is divided into four domains with the center line in parallel with the X-axis direction and the center line in parallel with the Y-axis direction defined as boundaries. A plurality of slits **15a** extending in a direction at an angle of 45 degrees to the X axis are formed in a first domain (upper right domain). A plurality of slits **15a** extending in a direction at an angle of 135 degrees to the X axis are formed in a second domain (upper left domain). A plurality of slits **15a** extending in a direction at an angle of 225 degrees to the X axis are formed in a third domain (lower left domain). A plurality of slits **15a** extending in a direction at an angle of 315 degrees to the X axis are formed in a fourth domain (lower right domain). A vertical alignment film (not illustrated) made of polyimide is formed on the picture element electrode **15**.

Black matrices, color filters and a common electrode are formed in the other substrate. The black matrices are made of a metal such as Cr (chromium), or of black resin. The black matrices are arranged respectively in positions, each of which is opposite to any one of the gate bus lines **11**, the data bus lines **12** and the TFTs **14**. The color filters are classified into three types, such as red, green and blue. Any one of the three types of color filters is arranged in each of the picture elements. The common electrode is made of a transparent conductive material such as ITO, and is formed on the color filters. A vertical alignment film made of polyimide is formed on the common electrode.

A liquid crystal panel is constituted in the following manner. These substrates are arranged to be opposite to each other with spacers (not illustrated) interposed between the two substrates. Liquid crystal with negative dielectric anisotropy is filled between the two substrates. Hereinafter, out of the two substrates constituting the liquid crystal panel, one substrate on which a TFT is formed will be termed as a TFT substrate, and the other substrate which is arranged to be opposite to the TFT substrate will be termed as an opposing substrate.

In the case of the MVA mode liquid crystal display device shown in FIG. 1, the liquid crystal molecules are aligned virtually perpendicularly to the surface of each of the substrates while voltage is not being applied to the picture element electrode **15**. When voltage is applied to the picture element electrode **15**, the liquid crystal molecules **10** tilt in the directions in which the respective slits **15a** extend as schematically shown in FIG. 1. Accordingly, four domains are formed in any of the picture elements while the directions in which the liquid crystal molecules tilt vary from one domain to another. This inhibits light from leaking in oblique directions, and thus securing good viewing angle characteristics.

Changing the subject. In the case of the MVA mode liquid crystal display device shown in FIG. 1, it remains to be determined whether the liquid crystal molecules **10** tilt inwards (in directions of the center of the picture element) or outwards (in directions of the outside of the picture element), immediately after voltage is applied to the picture element electrode **15**. First of all, the electric field in extremities of the

picture element electrode **15** determines the liquid crystal molecules **10** in extremities of the slits **15a** (near the data bus line **12**) to tilt inwards. Subsequently, the liquid crystal molecules **10** in positions inwards from the extremities tilt towards the center of the picture element. Then, the liquid crystal molecules **10** in positions further inwards from the extremities tilt towards the center of the picture element. This process is repeated until all the liquid crystal molecules tilt towards the center of the picture element. Accordingly, it takes time for all the liquid crystal molecules **10** in a picture element to complete tilting in predetermined directions. This brings about a problem that the response time is long.

The aforementioned Japanese Patent Laid-open Official Gazette No. 2003-149647 has disclosed that a liquid crystal display device is fabricated in the following manner. First, liquid crystal to which a polymer component (monomer) is added is filled into the space between the pair of the substrates. Then, voltage is applied between the picture element electrode and the common electrode, thereby causing the liquid crystal to align in predetermined directions. Thereafter, beams of ultraviolet light are irradiated to the polymer component, and thereby the polymer component is polymerized. By this, polymer is made in the liquid crystal layer. In the case of the liquid crystal display device thus fabricated, the polymer in the liquid crystal layer determines directions in which the liquid crystal molecules tilt. For this reason, no sooner is voltage applied between the picture element electrode and the common electrode than all of the liquid crystal molecules in the picture element start to tilt in predetermined directions. Accordingly, the response time is reduced to a large extent.

In addition, addition of a polymer component to liquid crystal has been disclosed, also, by Japanese Patent Laid-open Official Gazette No. Hei. 11-95221 and Japanese Patent Laid-open Official Gazette No. Hei. 8-36186.

In general, in the case of a vertical alignment (VA) mode liquid crystal display device, it has been known that the gray-scale brightness characteristics to be observed when the liquid crystal display device is viewed from the front is different from that to be observed when the liquid crystal display device is viewed in an oblique direction. The aforementioned MVA mode liquid crystal display device also has the same defect. FIG. 2 is a diagram showing a gray-scale brightness characteristics to be observed when the MVA mode liquid crystal display device is viewed from the front, and a gray-scale brightness characteristics to be observed when the MVA mode liquid crystal display device is viewed in a direction at an azimuth angle of 90 degrees and at a polar angle of 60 degrees (in a direction downwards diagonally). In FIG. 2, the axis of abscissa represents the gray scale, and the axis of ordinate represents the transmittance. It should be noted that, in this patent application, the center of the liquid crystal panel is defined as the origin of ordinates, an angle between the x axis of the liquid crystal panel and a line along which a line of sight is projected onto the liquid crystal panel is termed as an azimuth angle, and an angle between a normal line of the liquid crystal panel and the line of sight is termed as a polar angle. Brightness between black and white is divided into 256 gray scales in FIG. 2. Each gray scale corresponds to applied voltage to a picture element electrode. The larger the gray scale number is, the larger voltage is applied to the picture element electrode. Furthermore, in FIG. 2, a transmittance is indicated by a value relative to the transmittance ( $T_{white}$ ) which is defined as 1 (one) when white is displayed.

As understood from FIG. 2, in the case of the conventional MVA mode liquid crystal display device, the gray-scale transmittance characteristics to be observed when the liquid crystal display device is viewed from the front is much different

from that to be observed when the liquid crystal display device is viewed in an oblique direction. For this reason, the conventional MVA mode liquid crystal display device has a disadvantage that the display quality is deteriorated when viewed in an oblique direction although a preferable display quality can be obtained when viewed from the front. In particular, as understood from FIG. 2, the line representing the gray-scale transmittance characteristics to be observed when the liquid crystal is viewed in the oblique direction undulates to a large extent in comparison with the line representing the gray-scale transmittance characteristics to be observed when the liquid crystal display device is viewed from the front. Accordingly, when middle gray-scales are displayed, the difference in brightness becomes smaller between the viewing from the front and the viewing in the oblique direction. For this reason, a phenomenon occurs in which an image to be viewed in the oblique direction looks whitish (washes out) in comparison with that to be viewed from the front, thus deteriorating the display quality. Moreover, an anisotropy in terms of a refractive index of the liquid crystal has wavelength dependency. For this reason, color to be seen when the conventional MVA mode liquid crystal display device is viewed from the front is much different from that to be seen when the conventional MVA mode liquid crystal display device is viewed in the oblique direction in some cases.

Furthermore, the slits 15a of the picture element electrode 15 as shown in FIG. 1 are formed by use of a photolithography technique. Unevenness of the thickness of a photoresist film and a slight difference (shot irregularity) in exposure during stepper exposure make the widths of the respective slits 15a ununiformed. This causes optical characteristics of the picture element to be irregular, thus constituting a cause of display unevenness. For example, when a display is performed with middle gray scales in the entire surface of the panel, tile-shaped patterns appear in some cases.

Additionally, improvement of the substantial aperture ratio and further reduction in power consumption have been awaited. In addition, in the case of a recent liquid crystal display device, further improvement in its response characteristics has been awaited.

#### SUMMARY OF THE INVENTION

With the aforementioned matters taken into consideration, an object of the present invention is to provide a MVA mode liquid crystal display device whose substantial aperture ratio is higher so as to be applicable to a notebook personal computer, and which is better at the display quality even when viewed in an oblique direction.

Another object of the present invention is to provide a MVA mode liquid crystal display device whose substantial aperture ratio can be further improved.

Yet another object of the present invention is to provide a MVA mode liquid crystal display device, whose substantial aperture ratio is higher so as to be applicable to a notebook personal computer, which prevents display unevenness from occurring due to a photolithography process, and which accordingly is better at the display quality.

Still another object of the present invention is to provide a MVA mode liquid crystal display device whose substantial aperture ratio is higher so as to be applicable to a notebook personal computer, and which is better at the response characteristics.

The aforementioned problems are solved by a liquid crystal display device which has the following configuration. The liquid crystal display device includes: a first and a second

liquid crystal with negative dielectric anisotropy which is contained between the first and the second substrates; and a polymer which is made by polymerizing a polymer component added to the liquid crystal, and which determines a direction in which liquid crystal molecules tilt when voltage is applied. In the first substrate, a switching element, a first sub picture element electrode and a second sub picture element electrode are formed for each picture element. The first sub picture element electrode is constituted of a plurality of band-shaped microelectrode parts, and a connecting electrode part which electrically connects the microelectrode parts with one another. The second sub picture element electrode is constituted of a plurality of band-shaped microelectrode parts, and a connecting electrode part which electrically connects the microelectrode parts with one another. In the second substrate, a common electrode which is opposite to the first and the second sub picture element electrodes is formed. First voltage is applied to the first sub picture element electrode through the switching element. Second voltage which is lower than the first voltage is applied to the second sub picture element electrode.

In the case of the present invention, voltage, which is lower than that to be applied to the first sub picture element electrode, is applied to the second sub picture element electrode. If there were a plurality of fields whose applied voltages are different from each other in a single picture element in the aforementioned manner, this inhibits a phenomenon (termed as "wash out") in which the screen would otherwise look whitish when being viewed in an oblique direction. Accordingly, the display quality is improved.

The aforementioned problem is solved by a liquid crystal display device which has the following configuration. The liquid crystal display device includes: a first and a second substrates which are arranged to be opposite to each other; liquid crystal with negative dielectric anisotropy which is contained between the first and the second substrates; and a polymer which is made by polymerizing a polymer component added to the liquid crystal, and which determines a direction in which liquid crystal molecules tilt when voltage is applied. In the first substrate, a switching element and a picture element electrode are formed for each picture element. The picture element electrode is constituted of a plurality of band-shaped microelectrode parts and a connecting electrode part which electrically connects the microelectrode parts with one another. The microelectrode part has a notch in a portion of its extremity, the portion being opposite to no neighboring microelectrode part.

Liquid crystal molecules between a microelectrode part and a bus line are aligned in a direction which is different from a direction in which the microelectrode part extends. This causes a dark portion between the microelectrode part and the bus line, thus constituting a cause for decreasing the substantial aperture ratio. If the interval between the microelectrode part and the bus line were made smaller, this makes smaller an area where the dark portion occurs, thus enabling the substantial aperture ratio to be improved. In this case, however, the capacitance between the microelectrode part and the bus line becomes larger. This deteriorates the display quality due to the crosstalk.

Meanwhile, the portion of the extremity of the microelectrode part, which portion is opposite to no neighboring microelectrode part, makes no contribution to aligning the liquid crystal molecules in predetermined directions. In addition, the portion constitutes a cause for increasing a parasitic capacitance between the microelectrode part and the bus line. With this taken into consideration, in the case of the present invention, a notch is provided to the portion of the extremity

of the microelectrode part, which portion is opposite to no neighboring microelectrode part. Thereby, the crosstalk can be inhibited from occurring, and the substantial aperture ratio can be improved.

The aforementioned problem is solved by a liquid crystal display device which has the following configuration. The liquid crystal display device includes: a first and a second substrates which are arranged to be opposite to each other; liquid crystal with negative dielectric anisotropy which is contained between the first and the second substrates; and a polymer which is made by polymerizing a polymer component added to the liquid crystal, and which determines a direction in which liquid crystal molecules tilt when voltage is applied. In the first substrate, a switching element and a picture element electrode are formed for each picture element. The picture element electrode is constituted of a plurality of band-shaped microelectrode parts, and a connecting electrode part which electrically connects the microelectrode parts with one another. A shape of an area between two neighboring microelectrode parts, which area is located near the base ends of the two neighboring microelectrode parts, is symmetrical along the center line of the area between two neighboring microelectrode parts.

If the shape of an area between two neighboring microelectrodes, which area is located near the base ends of the two neighboring microelectrode parts, were symmetrical along the center line of the area between two neighboring microelectrode parts as described above, this enables liquid crystal molecules in the area to be aligned in the same direction as the microelectrode parts extend. Thereby, the dark portion is inhibited from occurring, and accordingly the substantial aperture ratio is improved.

The aforementioned problem is solved by a liquid crystal display device which has the following configuration. The liquid crystal display device includes: a first and a second substrates which are arranged to be opposite to each other; liquid crystal with negative dielectric anisotropy which is contained between the first and the second substrates; and a polymer which is made by polymerizing a polymer component added to the liquid crystal, and which determines a direction in which liquid crystal molecules tilt when voltage is applied. In the first substrate, a switching element and a picture element electrode are formed for each picture element. The picture element electrode is constituted of a plurality of band-shaped microelectrode parts, and a connecting electrode part which electrically connects the microelectrode parts with one another. The microelectrode part includes a notch in the portion of the extremity of the microelectrode part, which portion is opposite to no neighboring microelectrode part. A shape of an area between two neighboring microelectrode parts, which area is located near the base ends of the two neighboring microelectrode parts, is symmetrical along the center line of the area between two neighboring microelectrode parts.

In the case of the present invention, alignment disorder of the liquid crystal molecules are inhibited in the area between two neighboring microelectrode parts, which area is located near the base ends of the two neighboring microelectrodes, and also in the area between two neighboring microelectrode parts, which area is located near the extremities of the two neighboring microelectrode parts. Accordingly, the substantial aperture ratio can be further improved. This enables the liquid crystal display device to consume far less electric power.

The aforementioned problem is solved by a liquid crystal display device which has the following configuration. The liquid crystal display device includes: a first and a second

substrates which are arranged to be opposite to each other; liquid crystal with negative dielectric anisotropy which is contained between the first and the second substrates; and a polymer which is made by polymerizing a polymer component added to the liquid crystal, and which determines a direction in which liquid crystal molecules tilt when voltage is applied. In the first substrate, each picture element is provided with: a gate bus line, a data bus line, an auxiliary capacitance bus line, a switching element, a first sub picture element electrode, a second picture element electrode, an auxiliary capacitance electrode, control electrodes, and auxiliary capacitance lower electrodes. The gate bus line extends in a direction. The data bus line extends in a direction which crosses the gate bus line. The auxiliary capacitance bus line is in parallel with the gate bus line. The switching element is formed in each of picture element regions defined by the gate bus lines and the data bus lines. The first sub picture element electrode is constituted of a plurality of band-shaped microelectrode parts, and a connecting electrode part which electrically connects the microelectrode parts with one another. The first sub picture element electrode includes a plurality of domain control fields which are different from one another in alignment direction of liquid crystal molecules, and is directly connected with the switching element. The second sub picture element electrode is arranged in the same picture element region as the first sub picture element electrode is, and is constituted of a plurality of band-shaped microelectrode parts, and a connecting electrode part which electrically connects the microelectrode parts with one another. The second sub picture element electrode includes a plurality of domain control fields which are different from one another in alignment direction of liquid crystal molecules. The auxiliary capacitance electrode is arranged in a position opposite to the auxiliary capacitance bus line with a first insulating film interposed therebetween. The control electrodes are connected to the switching element, and are arranged respectively in a position opposite to a boundary between a domain control field of the first sub picture element electrode and a corresponding domain control field of the second sub picture element electrode, and in a position opposite to a boundary between another domain control field of the first sub picture element electrode and another corresponding domain control field of the second sub picture element electrode. The control electrodes are capacitively coupled to the corresponding second sub picture element electrodes through a second insulating film. The auxiliary capacitance lower electrodes are connected to the auxiliary capacitance bus line, and are arranged in positions opposite respectively to the control electrodes with the first insulating film interposed therebetween. In the second substrate, a common electrode which is opposite to the first and the second sub picture element electrodes is formed.

In the case of the present invention, the control electrode and the auxiliary capacitance lower electrode are arranged with the first insulating film interposed therebetween, in the position opposite to the boundary between a domain control field of the first sub picture element electrode and a corresponding domain control field of the second sub picture element electrode. This increases a capacitance value of an auxiliary capacitance connected to a picture element electrode in parallel, thus improving the response characteristics.

The aforementioned problem is solved by a liquid crystal display device which has the following configuration. The liquid crystal display device includes: a first and a second substrates which are arranged to be opposite to each other; liquid crystal with negative dielectric anisotropy which is contained between the first and the second substrates; and a

polymer which is made by polymerizing a polymer component added to the liquid crystal, and which determines a direction in which liquid crystal molecules tilt when voltage is applied. In the first substrate, a switching element, and a picture element electrode which is divided into a plurality of fields which are different from one another in alignment direction of liquid crystal molecules are formed for each picture element. With regard to the picture element electrode, each of its fields is constituted of a plurality of band-shaped microelectrode parts, and a connecting electrode part which electrically connects the microelectrode parts with one another. The width of the microelectrode part corresponding to an edge of the picture element is larger than that corresponding to a center portion of the picture element.

If the width of the microelectrode part corresponding to an edge of the picture element were larger than that corresponding to a center portion of the picture element in this manner, this can avoid display unevenness which would otherwise occur due to a photolithography process.

The aforementioned problem is solved by a liquid crystal display device which has the following configuration. The liquid crystal display device includes: a first and a second substrates which are arranged to be opposite to each other; liquid crystal with negative dielectric anisotropy which is contained between the first and the second substrates; and a polymer which is made by polymerizing a polymer component added to the liquid crystal, and which determines a direction in which liquid crystal molecules tilt when voltage is applied. In the first substrate, a switching element, a first sub picture element electrode and a second sub picture element electrode are formed for each picture element. The first sub picture element electrode is divided into a plurality of fields which are different from one another in alignment direction of liquid crystal molecules. The second sub picture element electrode is divided into a plurality of fields which are different from one another in alignment direction of liquid crystal molecules. With regard to the first sub picture element electrode, each of its fields is constituted of: a plurality of band-shaped microelectrode parts extending in a predetermined direction; and a connecting electrode part which electrically connects the microelectrode parts with one another. The first sub picture element electrode is directly connected to the switching element. With regard to the second sub picture element electrode, each of its fields is constituted of: a plurality of band-shaped microelectrode parts extending in a predetermined direction; and a connecting electrode part which electrically connects the microelectrode parts with one another. The second sub picture element electrode is connected to the switching element through capacitive coupling. The width of each of the microelectrode parts in the first sub picture element electrode is larger than the width of each of the microelectrode parts in the second sub picture element electrode.

If, as described above, the width of each of the microelectrode parts in the first sub picture element electrode directly connected to the switching element were larger than the width of each of the microelectrode parts in the second sub picture element electrode connected to the switching element through capacitive coupling, this can avoid display unevenness which would otherwise occur due to a photolithography process.

The aforementioned problem is solved by a liquid crystal display device which has the following configuration. The liquid crystal display device includes: a first and a second substrates which are arranged to be opposite to each other; liquid crystal with negative dielectric anisotropy which is contained between the first and the second substrates; and a

polymer which is made by polymerizing a polymer component added to the liquid crystal, and which determines a direction in which liquid crystal molecules tilt when voltage is applied. With regard to the first substrate, a switching element as well as a first and a second sub picture element electrodes are formed in each of its picture elements. The first sub picture element electrode is divided into a plurality of fields which are different from one another in alignment direction of liquid crystal molecules. The second sub picture element electrode is divided into a plurality of fields which are different from one another in alignment direction of liquid crystal molecules. With regard to the first sub picture element electrode, each of its fields is constituted of a plurality of band-shaped microelectrode parts extending in a predetermined direction, and a connecting electrode part which electrically connects the microelectrode parts with one another. The first sub picture element electrode is directly connected to the switching element. With regard to the second sub picture element electrode, each of its fields is constituted of a plurality of band-shaped microelectrode parts extending in a predetermined direction, and a connecting electrode part which electrically connects the microelectrode parts with one another. The second sub picture element electrode is connected to the switching element through capacitive coupling. Ten percent to seventy percent is a ratio of an area of the first sub picture element electrode to a sum of the area of the first sub picture element electrode and an area of the second sub picture element electrode.

If an area ratio of the first sub picture element electrode directly connected to the switching element were in a range of 10% to 70%, this can inhibit a phenomenon in which the screen looks whitish while viewed in an oblique direction.

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a plan view showing an example of a conventional MVA mode liquid crystal display device.

FIG. 2 is a diagram showing gray-scale brightness characteristics to be observed when the conventional MVA mode liquid crystal display device is viewed from the front and gray-scale brightness characteristics to be observed when the conventional MVA mode liquid crystal display device is viewed in a direction at an azimuth angle of 90 degrees and at a polar angle of 60 degrees.

FIG. 3 is a plan view showing a liquid crystal display device according to a first embodiment of the present invention.

FIG. 4 is a cross-sectional schematic view showing the liquid crystal display device according to the first embodiment.

FIG. 5 is a diagram showing transmittance-applied voltage characteristics to be observed when the liquid crystal display device according to the first embodiment is viewed from the front, and transmittance-applied voltage characteristics to be observed when the liquid crystal display device according to the first embodiment is viewed in an oblique direction.

FIG. 6 is a plan view showing a liquid crystal display device according to a second embodiment of the present invention.

FIG. 7 is a plan view showing a liquid crystal display device according to a third embodiment of the present invention.

FIG. 8 is a plan view showing a liquid crystal display device according to a fourth embodiment of the present invention.

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FIG. 9 is a plan view showing a liquid crystal display device according to a fifth embodiment of the present invention.

FIG. 10 is a schematic diagram showing alignment of liquid crystal molecules in the case of an MVA mode liquid crystal display device.

FIG. 11 is a plan view, and a partially enlarged view of the plan view, both showing a liquid crystal display device according to a first example of a sixth embodiment of the present invention.

FIG. 12 is a plan view, and a partially enlarged view of the plan view, both showing a liquid crystal display device according to a second example of the sixth embodiment of the present invention.

FIG. 13 is a plan view, and a partially enlarged view of the plan view, both showing a liquid crystal display device according to a third example of the sixth embodiment of the present invention.

FIG. 14 is a plan view showing a liquid crystal display device according to a seventh embodiment of the present invention.

FIG. 15 is a cross-sectional view taken along the I-I line in FIG. 14.

FIG. 16 is a diagram showing relationship between a capacitance ratio of a picture element and a voltage ratio.

FIG. 17 is a diagram showing transmittance characteristics and alignment characteristics in the case of the liquid crystal display device according to the seventh embodiment.

FIG. 18 is a plan view showing a liquid crystal display device according to an eighth embodiment of the present invention.

FIG. 19 is a diagram showing transmittance characteristics and alignment characteristics in the case of the liquid crystal display device according to the eighth embodiment.

FIG. 20 is a plan view showing another example of a liquid crystal display device according to the eighth embodiment.

FIG. 21 is a plan view showing a liquid crystal display device according to a ninth embodiment of the present invention.

FIG. 22 is a diagram showing transmittance characteristics in the case of the liquid crystal display device according to the ninth embodiment.

FIGS. 23A and 23B are diagrams respectively showing a light transmission condition to be observed when voltage is applied in the case of a liquid crystal display device (without black matrices) in which an interval between a microelectrode part and a data bus line is 7  $\mu\text{m}$ , and a light transmission condition to be observed when voltage is applied in the case of a liquid crystal display device (without black matrices) in which an interval between a microelectrode part and a data bus line is 5  $\mu\text{m}$ .

FIGS. 24A and 24B are diagrams respectively showing a light transmission condition to be observed when voltage is applied in the case of a liquid crystal display device (with black matrices) in which an interval between a microelectrode part and a data bus line is 7  $\mu\text{m}$ , and a light transmission condition to be observed when voltage is applied in the case of a liquid crystal display device (with black matrices) in which an interval between a microelectrode part and a data bus line is 5  $\mu\text{m}$ .

FIGS. 25A and 25B are diagrams showing a result of examining transition characteristics of a liquid crystal display device from a time when voltage is applied to the liquid crystal till a time when alignment of the liquid crystal becomes stable by use of a high-speed camera.

FIG. 26 is a plan view showing a liquid crystal display device according to a first example of a tenth embodiment.

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FIG. 27 is a plan view showing a liquid crystal display device according to a second example of the tenth embodiment.

FIG. 28 is a plan view showing a liquid crystal display device according to a third example of the tenth embodiment.

FIG. 29 is a plan view showing a liquid crystal display device according to a fourth example of the tenth embodiment.

FIG. 30 is a diagram showing relationship among white display voltage, a directly-connected picture element electrode ratio and an amount of difference in gamma values.

FIG. 31 is a plan view showing a liquid crystal display device (Part 1) according to an eleventh embodiment of the present invention.

FIG. 32 is a plan view showing the liquid crystal display device (Part 2) according to the eleventh embodiment of the present invention.

FIG. 33 is a plan view showing the liquid crystal display device (Part 3) according to the eleventh embodiment of the present invention.

FIG. 34 is a plan view showing the liquid crystal display device (Part 4) according to the eleventh embodiment of the present invention.

## DESCRIPTION OF THE PREFERRED EMBODIMENTS

Hereinbelow, descriptions will be provided for embodiments of the present invention with reference to the attached drawings.

### First Embodiment

FIG. 3 is a plan view of a liquid crystal display device according to a first embodiment of the present invention. FIG. 4 is a cross-sectional schematic view of the liquid crystal display device according to the first embodiment. Incidentally, FIG. 3 shows two picture element regions.

As shown in FIG. 4, a liquid crystal panel 100 is constituted of: a TFT substrate 110; an opposing substrate 130; and a liquid crystal layer 140, made of liquid crystal with negative dielectric anisotropy, which is contained in the space between the TFT substrate 110 and the opposing substrate 130. Polarizing plates 141a and 141b are arranged respectively on the two sides in the thickness direction of this liquid crystal panel 100. The liquid crystal layer 140 includes a polymer which has been formed in the following process. Polymer components (monomer or oligomer) are added to the liquid crystal, and beams of ultraviolet light are irradiated to the polymer components. Thereby, the polymer components are polymerized into the polymer.

A plurality of gate bus lines 112 extending in the horizontal direction (X-axis direction) and a plurality of data bus lines 117 extending in the vertical direction (Y-axis direction) are formed in the TFT substrate 110, as shown in FIG. 3. Each of rectangles defined by these gate bus lines 112 and these data bus lines 117 is a picture element region. In addition, auxiliary capacitance bus lines 113 which are arranged respectively in parallel with the gate bus lines 112, and each of which traverses the center of the picture element region, is formed in the TFT substrate 110. In the case of this embodiment, the absorption axis of one of the polarizing plates 141a and 141b is arranged in parallel with the gate bus line 112, and the absorption axis of the other of the polarizing plates 141a and 141b is arranged in parallel with the data bus line 117.

A TFT 118, three sub picture element electrodes 121a to 121c, control electrodes 119a and 119c and an auxiliary

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capacitance electrode **119b** are formed in each of the picture element regions. The sub picture element electrodes **121a** to **121c** are made of a transparent conductive material such as ITO. Each of the sub picture element electrodes **121a** to **121c** is provided with slits **122** which regulate alignment directions respectively of liquid crystal molecules when voltage is applied.

Hereinbelow, detailed descriptions will be provided for the structure of the TFT substrate **110** and the opposing substrate **130** with reference to the plan view of FIG. 3 and the cross-sectional schematic view of FIG. 4.

The gate bus lines **112** and the auxiliary capacitance bus lines **113** are formed in a glass substrate **111** which is a base for the TFT substrate **110**. These gate bus lines **112** and these auxiliary capacitance bus lines **113** are formed respectively of a metallic film into which, for example, Al (Aluminum) and Ti (Titanium) are laminated.

A first insulating film **114** (gate insulating film) made, for example, of SiO<sub>2</sub>, SiN or the like is formed over the gate bus lines **112** and the auxiliary capacitance bus lines **113**. A semiconductor film **115** (for example, an amorphous silicon film or a polysilicon film) which is an active layer of the TFT **118** is formed in each predetermined area on the first insulating film **114**. A channel protecting film **116** made of SiN or the like is formed on top of the semiconductor film **115**. A drain electrode **118a** and a source electrode **118b** of the TFT **118** are formed respectively on the two sides of the channel protecting film **116**.

In addition, the data bus lines **117** connected respectively to the source electrodes **118b** of the TFTs **118**, the control electrodes **119a** and **119c** connected respectively to the drain electrodes **118a** of the TFTs **118**, and the auxiliary capacitance electrodes **119b** are formed on the first insulating film **114**. As shown in FIG. 4, the auxiliary capacitance electrodes **119b** are formed in the respective positions opposite to the auxiliary capacitance bus lines **113** with the first insulating film **114** interposed between the auxiliary capacitance electrodes **119b** and the corresponding auxiliary capacitance bus lines **113**. Each of an auxiliary capacitance is constituted of the auxiliary capacitance bus line **113**, the auxiliary capacitance electrode **119b** and the first insulating film **114** which is interposed between the auxiliary capacitance bus line **113** and the auxiliary capacitance electrode **119b**. The control electrodes **119a** and **119c** are formed so as to be along the center line of each of the picture element regions, the center line being in parallel with the Y axis. The auxiliary capacitance electrode **119b** is formed so as to be along the center line of each of the picture element region, the center line being in parallel with the X axis.

The data bus lines **117**, the drain electrodes **118a**, the source electrodes **118b**, the control electrodes **119a** and **119c**, and the auxiliary capacitance electrodes **119b** are formed respectively of metallic films into which Ti, Al and Ti are laminated.

A second insulating film **120** made, for example, of SiN is formed over the data bus lines **117**, the drain electrodes **118a**, the source electrodes **118b**, the control electrodes **119a** and **119c**, and the auxiliary capacitance electrodes **119b**. Groups constituting of three sub picture element electrodes **121a** to **121c** are formed on the second insulating film **120**. As shown in FIG. 4, each of the sub picture element electrodes **121a** is capacitively coupled to the corresponding control electrode **119a** with the second insulating film **120** interposed between the sub picture element electrode **121a** and the control electrode **119a**. Each of the sub picture element electrodes **121c** is capacitively coupled to the corresponding control electrode **119c** with the second insulating film **120** interposed between

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the sub picture element electrode **121c** and the control electrode **119c**. In addition, each of the sub picture element electrodes **121b** is electrically connected to the corresponding auxiliary capacitance electrode **119b** through a corresponding one of contact holes **120a** which are made in the second insulating film **120**.

As shown in FIG. 3, the sub picture element electrode **121a** is arranged in an upper portion in the Y-axis direction of each of the picture element regions. In addition, the sub picture element electrode **121a** is divided into the two bilaterally symmetrical fields (domain control fields) with the center line in parallel with the Y axis defined as the boundary. In each of the picture elements, a plurality of slits **122** extending in a direction at an angle of approximately 45 degrees to the X axis are formed in the right field. A plurality of slits **122** extending in a direction at an angle of approximately 135 degrees to the X axis are formed in the left field.

The sub picture element electrode **121b** is positioned in the center of each of the picture element regions, and is divided into four fields (domain control fields) by the center line in parallel with the X axis and the center line in parallel with the Y axis. A plurality of slits **122** extending in a direction at an angle of approximately 45 degrees to the X axis are formed in a first field located upper right. A plurality of slits **122** extending in a direction at an angle of approximately 135 degrees to the X axis are formed in a second field located upper left. A plurality of slits **122** extending in a direction at an angle of approximately 225 degrees to the X axis are formed in a third field located lower left. A plurality of slits **122** extending in a direction at an angle of approximately 315 degrees to the X axis are formed in a fourth field located lower right.

The sub picture element electrode **121c** is arranged in a lower portion in the Y-axis direction of each of the picture element regions. In addition, the sub picture element electrode **121c** is divided into the two bilaterally symmetrical fields (domain control fields) with the center line in parallel with the Y axis defined as the boundary. A plurality of slits **122** extending in a direction at an angle of approximately 225 degrees to the X axis are formed in the left field. A plurality of slits **122** extending in a direction at an angle of approximately 315 degrees to the X axis are formed in the right field. The width of each of the slits **122** respectively of the sub picture element electrodes **121a** to **121b** is, for example, 3.5  $\mu$ m. The interval between each two neighboring slits (the width of a microelectrode part) is, for example, 6  $\mu$ m.

It should be noted that, in the specification for this patent application, a conductor part, shaped like a belt, between each two neighboring slits in each of the picture element electrodes and in each of the sub picture element electrodes is termed as a microelectrode part, and a part which electrically connects base ends respectively of the microelectrode parts is termed as a connecting electrode part.

A vertical alignment film (not illustrated) made of polyimide or the like is formed over the sub picture element electrodes **121a** to **121b**.

On the other hand, black matrices (light blocking films) **132**, color filters **133** and a common electrode **134** are formed in one surface (on the lower side in FIG. 4) of a glass substrate **131** which is a base of the opposing substrate **130**.

The black matrices **132** are arranged respectively in positions opposite to the gate bus lines **112**, the data bus lines **117** and the TFTs **118** in the TFT substrate **110**. Color filters **133** are classified into three types, such as red, green and blue. A color filter with any one of the three colors is arranged in each of the picture element regions. One pixel is constituted of three neighboring picture elements of a red picture element, a

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green picture element and a blue picture element. The pixel is designed to be capable of displaying various colors.

The common electrode **134** is formed of a transparent conductive material such as ITO, and is arranged on the color filter **133** (on the lower side of the color filter **133** in FIG. 4). A vertical alignment film (not illustrated) made of polyimide or the like is formed on the common electrode **134** (on the lower side of the common electrode **134** in FIG. 4).

In the case of the liquid crystal display device thus configured according to this embodiment, when a display signal is applied to the data bus lines **117** and concurrently a predetermined voltage (scan signal) is applied to the gate bus lines **112**, the TFTs **118** are turned on. Thereby, a display signal is transmitted to the control electrodes **119a** and **119c** as well as the auxiliary capacitance electrodes **119b**. With regard to each of the picture elements, since the sub picture element electrode **121b** is connected to the auxiliary capacitance electrode **119b** through the contact hole **120a**, the voltage of the sub picture element electrode **121b** is equal to the voltage of the display signal.

On the other hand, voltage corresponding to a capacitance value between the sub picture element electrode **121a** and the control electrode **119a** is applied to the sub picture element electrode **121a**, and voltage corresponding to a capacitance value between the sub picture element electrode **121c** and the control electrode **119c** is applied to the sub picture element electrode **121c**. At this point, voltage **V1** to be applied commonly to the sub picture element electrodes **121a** and **121c** is expressed by

$$V1 = VD \cdot C2 / (C1 + C2)$$

while the voltage of the display signal is denoted by **VD**; a capacitance value between a group of the sub picture element electrodes **121a** and **121c** as well as a group of the common electrode **134** is denoted by **C1**; and a capacitance value between a group of the sub picture element electrodes **121a** and **121c** as well as a group of the control electrodes **119a** and **119c** is denoted by **C2**.

In other words, voltage, which is lower than the voltage to be applied to the sub picture element electrode **121b**, is applied commonly to the sub picture element electrodes **121a** and **121c**. This means that one picture element has two types of fields which are different from each other in transmittance-applied voltage characteristics (TV characteristics). In addition, the summation of the transmittance-applied voltage characteristics respectively of the two types of fields represents the transmittance-applied voltage characteristics of the overall picture element. It has been known that, if a plurality of types of fields which are different from one another in transmittance-applied voltage characteristics were formed in a single picture element, this can avoid deterioration in quality of display to be performed when the screen is viewed in an oblique direction.

In the case of this embodiment, the capacitance values **C1** and **C2** are set in a way that 1 volt is the difference between a threshold value of the transmittance-applied voltage in the field where the sub picture element electrode **121b** (i.e. a sub picture element electrode connected to the TFT through no capacitive coupling: hereinafter, referred to as a "directly-connected picture element electrode") is arranged and a threshold value of the transmittance-applied voltage commonly in the fields where the respective sub picture element electrodes **121a** and **121c** (i.e. sub picture element electrodes connected to the TFT through capacitive coupling: hereinafter, referred to as "capacitively-coupled picture element electrodes") are arranged. Moreover, in the case of this embodiment, a ratio of an area of the field where the sub picture

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element electrode **121b** (directly-connected picture element electrode) is arranged to an area of the fields where the respective sub picture element electrodes **121a** and **121c** (capacitively-coupled picture element electrodes) are arranged is set at 4:6. The capacitance values **C1** and **C2** and the area ratio may be set as needed depending on a desired gray-scale brightness characteristics.

FIG. 5 is a diagram showing transmittance-applied voltage characteristics to be observed when the liquid crystal display device according to this embodiment (an example) is viewed from the front, and transmittance-applied voltage characteristics to be observed when the same liquid crystal display device is viewed in an oblique direction, while the horizontal axis represents the gray-scales and the vertical axis represents the transmittance. Incidentally, FIG. 5 additionally shows transmittance-applied voltage characteristics to be observed when a conventional liquid crystal display device with a structure as shown in FIG. 1 is viewed in an oblique direction. As learned from FIG. 5, a line representing the transmittance-applied voltage characteristics, which is observed when the liquid crystal display device according to this embodiment is viewed in the oblique direction, undulates less than a line representing the transmittance-applied voltage characteristics which is observed when the conventional liquid crystal display device as shown is viewed in the same oblique direction. It can be learned from this that the quality of display to be performed when the liquid crystal display device according to this embodiment is viewed in the oblique direction has been improved in comparison with the quality of display to be performed when the conventional liquid crystal display device as shown in FIG. 1 is viewed in the same oblique direction.

No beam of light is transmitted in areas surrounding a boundary between each two neighboring domains whose slits **122** extend in directions which are different from one domain to another, or in an area along the center line of each of the picture element regions which is in parallel with the X axis and in an area along the center line of the picture element region which is in parallel with the Y axis. This is because liquid crystal molecules in such areas are aligned in the direction in parallel with the X axis or the direction in parallel with the Y axis (i.e. in directions, in parallel with, or orthogonal to, the absorption axes respectively of the polarizing plates **141a** and **141b**) when voltage is applied. In the case of this embodiment, it is these boundary areas, but not other areas, where the control electrodes **119a** and **119c** and the auxiliary capacitance electrode **119b** are provided with regard to each of the picture elements. For this reason, reduction in the aperture ratio can be minimized, although provision of the control electrodes **119a** and **119c** as well as the auxiliary capacitance electrode **119b** to each of the picture elements inevitably reduces the aperture ratio.

Hereinbelow, descriptions will be provided for a method of manufacturing the liquid crystal display device according to this embodiment.

To begin with, the glass substrate **111** which is used as the base of the TFT substrate **110** is prepared. Subsequently, the metallic film into which, for example, Al (Aluminum) and Ti (Titanium) are laminated is formed on this glass substrate **111**. Thereafter, the metallic film is patterned by use of a photolithography process. Thus, the gate bus lines **112** and the auxiliary bus lines **113** are formed. In this occasion, for example, the gate bus lines **112** are formed with a pitch of approximately 300  $\mu\text{m}$  in the vertical direction.

Then, the first insulating film (gate insulating film) **114** made, for example, of an insulating material such as  $\text{SiO}_2$ ,  $\text{SiN}$  or the like is formed in the entire upper surface of the

glass substrate **111**. Thence, the semiconductor films (amorphous silicon films or polysilicon films) **115** which are used respectively as the active layers of the TFTs **118** are formed in predetermined positions on the first insulating film **114**.

Subsequently, the SiN film is formed in the entire upper surface of the glass substrate **111**. Thereafter, the SiN film is patterned by use of a photolithography process. Thereby, the channel protecting films **116** are formed respectively on top of areas which are used respectively as the channels of the semiconductor film **115**.

Then, an ohmic contact layer (not illustrated) made of a semiconductor film which has been treated with impurities in high concentration is formed in the entire upper surface of the glass substrate **111**. Thence, the metallic film into which, for example, Ti, Al and Ti are laminated in this order is formed on the glass substrate **111**. Thereafter, this metallic film and the ohmic contact layer are patterned by use of a photolithography process. Thus, the data bus lines **117**, the drain electrodes **118a**, the source electrodes **118b**, the control electrodes **119a** and **119c**, and the auxiliary capacitance electrodes **119b** are formed. In this occasion, for example, the data bus lines **117** are formed with a pitch of approximately 100  $\mu\text{m}$  in the horizontal direction.

The second insulating film **120** made of an insulating material such as  $\text{SiO}_2$ , SiN or the like is formed in the entire upper surface of the glass substrate **111**. Then, the contact holes **120a** which respectively reach the auxiliary capacitance electrodes **119b** are formed in the second insulating film **120**.

Then, the entire upper surface of the glass substrate **111** is sputtered with ITO. Thereby, the ITO film is formed. This ITO film is electrically connected with the auxiliary capacitance electrodes **119b** through the contact holes **120a**. Thereafter, the ITO film is patterned by use of a photolithography process. Thereby, the sub picture element electrodes **121a** to **121c** are formed. The slits **122** extending in oblique directions are formed in each of the sub picture element electrodes **121a** to **121c**, as described above.

Thence, the entire upper surface of the glass substrate **111** is coated with polyimide. Thereby, the alignment film is formed. Accordingly, the TFT substrate **110** is completed.

Next, descriptions will be provided for a method of fabricating the opposing substrate **130**.

To begin with, the glass substrate **131** which is used as the base of the opposing substrate **130** is prepared. Subsequently, the black matrices **132** are formed of Cr (Chromium) or black resin on the predetermined areas of the glass substrate **131**. The black matrices **132** are formed, for example, in the respective positions opposite to the gate bus lines **112** and the data bus lines **117** in the TFT substrate **110**.

Then, red color filters, green color filters and blue color filters **133** are formed on the glass substrate **131** respectively by use of red photosensitive resin, green photosensitive resin and blue photosensitive resin.

Thence, the entire upper surface of the glass substrate **131** is sputtered with ITO. Thereby, the common electrode **134** is formed. Thereafter, the common electrode **134** is coated with polyimide. By this, the alignment film is formed on the common electrode **134**. Accordingly, the opposing substrate **130** is completed.

The TFT substrate **110** and the opposing substrate **130**, which have been thus fabricated, are arranged to be opposite to each other. Thereafter, liquid crystal with negative dielectric anisotropy is filled into the space between the TFT substrate **110** and the opposing substrate **130**. The liquid crystal panel **100** is manufactured in this manner. A polymer component, for example, a polymer component (diacrylate, methacrylate or the like) with a photo-functional group, is before-

hand added to the liquid crystal by 0.3 wt %. In addition, the interval (cell gap) between the TFT substrate **110** and the opposing substrate **130** is, for example, 3.5  $\mu\text{m}$  to 4  $\mu\text{m}$ .

Subsequently, a predetermined signal is applied to the gate bus lines **112**, and thereby the TFT **118** of each of the picture elements is turned into an "on" state. In addition, a predetermined voltage is applied to the data bus lines **117**. Thereby, voltage is applied between the common electrode **134** and each of the sub picture element electrodes **121a** to **121c**. Accordingly, the liquid crystal molecules in each of the picture elements are aligned in predetermined directions. After the alignment of the liquid crystal molecules becomes sufficiently stable, beams of ultraviolet light are irradiated to the polymer component. Thereby, monomer in the liquid crystal layer is polymerized. The polymer thus made in the liquid crystal layer determines directions in which the respective liquid crystal molecules tilt when voltage is applied.

Thereafter, the polarizing plates **141a** and **141b** are arranged on the two sides of the liquid crystal panel **100** in the thickness direction. In addition, drive circuits and backlights are installed therein. In this manner, the liquid crystal display device according to this embodiment is completed.

#### Second Embodiment

FIG. **6** is a plan view showing a liquid crystal display device according to a second embodiment of the present invention. Incidentally, if components and equivalents in FIG. **6** were the same as, or similar to, those in FIG. **3**, the components and equivalents in FIG. **6** are denoted by the same reference numerals and symbols as those in FIG. **3** are. Thus, detailed descriptions will be omitted for the same, or similar components and equivalents in FIG. **6**.

In the case of this embodiment, two sub picture element electrodes **152a** and **152b** are formed in a single picture element region. The sub picture element electrodes **152a** (directly-connected picture element electrode) is arranged in a range upper in the Y axis direction in each of the picture element regions. The sub picture element electrode **152a** is divided into four fields (domain control fields) by the center line in parallel with the X axis and the center line in parallel with the Y axis. A plurality of slits **153** extending in a direction at an angle of approximately 45 degrees to the X axis are formed in a first field located upper right. A plurality of slits **153** extending in a direction at an angle of approximately 135 degrees to the X axis are formed in a second field located upper left. A plurality of slits **153** extending in a direction at an angle of approximately 225 degrees to the X axis are formed in a third field located lower left. A plurality of slits **153** extending in a direction at an angle of approximately 315 degrees to the X axis are formed in a fourth field located lower right.

The sub picture element **152b** (capacitively-coupled picture element electrode) is arranged in a range lower in the Y axis direction in each of the picture element regions. The area of the sub picture element electrode **152b** is larger than that of the sub picture element electrode **152a**. Like the sub picture element electrode **152a**, the sub picture element electrode **152b** is divided into four fields (domain control fields) by the center line in parallel with the X axis and the center line in parallel with the Y axis. A plurality of slits **153** extending in a direction at an angle of approximately 45 degrees to the X axis are formed in a first field located upper right. A plurality of slits **153** extending in a direction at an angle of approximately 135 degrees to the X axis are formed in a second field located upper left. A plurality of slits **153** extending in a direction at an angle of approximately 225 degrees to the X

axis are formed in a third field located lower left. A plurality of slits **153** extending in a direction at an angle of approximately 315 degrees to the X axis are formed in a fourth field located lower right.

Underneath the sub picture element electrodes **152a** and **152b**, a control electrode **151a** extending along a center line of each of the picture element regions is formed, the center line being in parallel with the Y axis. This control electrode **151a** is electrically connected with the drain electrode **118a** of each of the TFTs **118**.

In addition, underneath each of the sub picture element electrodes **152a**, an auxiliary capacitance bus line **113** and an auxiliary capacitance electrode **151b** are formed along a center line of the sub picture element electrode **152a**, the center line being in parallel with the X axis. The auxiliary capacitance bus line **113** is formed in the same layer as a gate bus line **112** is. In addition, the auxiliary capacitance electrode **151b** is formed in the same layer as the control electrode **151a** is, and is connected with the control electrode **151a**. A first insulating film (an equivalent to the insulating film **114** in FIG. 4) is formed between the auxiliary capacitance bus line **113** and the auxiliary capacitance electrode **151b**. An auxiliary capacitance is constituted of the first insulating film, the auxiliary capacitance bus line **113** and the auxiliary capacitance electrode **151b**. Furthermore, the auxiliary capacitance electrode **151b** is electrically connected with the sub picture element electrode **152a** through a contact hole **154**, which has been formed in a second insulating film (an equivalent to the insulating film **120** in FIG. 4).

Moreover, underneath each of the sub picture element electrodes **152b**, a control electrode **151c** is formed along a center line of the sub picture element electrode **152b**, the center line being in parallel with the X axis. The control electrode **151c** is formed in the same layer as the control electrode **151a** is, and is electrically connected with the control electrode **151a**. Additionally, the control electrode **151c** is capacitively coupled to the sub picture element electrode **152b** through the second insulating film.

The structure of an opposing substrate according to the second embodiment is basically the same as that according to the first embodiment, and descriptions will be omitted for the structure according to the second embodiment here. In addition, in the second embodiment, too, a polymer component such as diacrylate is added to liquid crystal, and the liquid crystal is filled into the space between a TFT substrate and the opposing substrate. Voltage is applied between a picture element electrode (each of the sub picture element electrodes **152a** and **152b**) and a common electrode. Thereby, liquid crystal molecules are aligned in predetermined directions. Thereafter, beams of ultraviolet light are irradiated to the polymer component. Accordingly, the polymer component is polymerized. Thus, a polymer is formed in the liquid crystal layer.

In the case of this embodiment, a single picture element is provided with two types of fields which are different from each other in transmittance-applied voltage characteristics in common with the first embodiment. This brings about an effect of avoiding deterioration in the display quality to be obtained when the screen is viewed in an oblique direction.

In addition, in the case of this embodiment, the auxiliary capacitance bus line **113** and the auxiliary capacitance electrode **151b** are formed along the center line of the sub picture element electrode **152a**, the center line being in parallel with the X axis. This portion constitutes a boundary between the two domains. Accordingly, when voltage is applied, the liquid crystal molecules tilt in a direction in parallel with the X axis. For this reason, light is not transmitted in this portion, even if

neither the auxiliary capacitance bus line **113** nor the auxiliary capacitance electrode **151b** were provided. This can avoid deterioration in the transmittance, which deterioration would otherwise be caused due to formation of the auxiliary capacitance bus line **113** and the auxiliary capacitance electrode **151b** in each of the picture elements. Additionally, in this embodiment, if the length and the width of the auxiliary capacitance electrode **151b** were adjusted, the capacitance value of the auxiliary capacitance can be controlled. This brings about an advantage of giving higher degree of freedom in designing the capacitance value of the auxiliary capacitance.

In common with the auxiliary capacitance bus line **113** and the auxiliary capacitance electrode **151b**, the control electrode **151c** is formed along the center line of the sub picture element electrode **152b**, the center line being in parallel with the X axis. This can avoid deterioration in the transmittance, which would otherwise be caused due to formation of the control electrode **151c** in each of the picture elements. Moreover, if the length and the width of the control electrode **151c** were adjusted, this can control the capacitance value of connection between the control electrode **151a** and the sub picture element electrode **152b** and the capacitance value of connection between the control electrode **151c** and the sub picture element electrode **152b**. This brings about an advantage of giving higher degree of freedom in designing the capacitance values of the respective connections.

### Third Embodiment

FIG. 7 is a plan view showing a liquid crystal display device according to a third embodiment of the present invention. If components and equivalents in FIG. 7 were the same as, or similar to, those in FIG. 3, the components and equivalents in FIG. 7 are denoted by the same reference numerals and symbols as those in FIG. 3 are. Thus, detailed descriptions will be omitted for the same, or similar, components and equivalents in FIG. 7.

In the case of this embodiment, too, two sub picture element electrodes **162a** and **162b** are formed in a single picture element region. The sub picture element electrode **162a** (directly-connected picture element electrode) is arranged in a range upper in the Y axis direction in each of the picture element regions. The sub picture element electrode **162a** is divided into four fields (domain control fields) by the center line in parallel with the X axis and the center line in parallel with the Y axis. A plurality of slits **163** extending in a direction at an angle of approximately 45 degrees to the X axis are formed in a first field located upper right. A plurality of slits **163** extending in a direction at an angle of approximately 135 degrees to the X axis are formed in a second field located upper left. A plurality of slits **163** extending in a direction at an angle of approximately 225 degrees to the X axis are formed in a third field located lower left. A plurality of slits **163** extending in a direction at an angle of approximately 315 degrees to the X axis are formed in a fourth field located lower right.

The sub picture element **162b** (capacitively-coupled picture element electrode) is arranged in a range lower in the Y axis direction in each of the picture element regions. The area of the sub picture element electrode **162b** is larger than that of the sub picture element electrode **162a**. Like the sub picture element electrode **162a**, the sub picture element electrode **162b** is divided into four fields (domain control fields) by the center line in parallel with the X axis and the center line in parallel with the Y axis. A plurality of slits **163** extending in a direction at an angle of approximately 315 degrees to the X

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axis are formed in a first field located upper right. A plurality of slits **163** extending in a direction at an angle of approximately 225 degrees to the X axis are formed in a second field located upper left. A plurality of slits **163** extending in a direction at an angle of approximately 135 degrees to the X axis are formed in a third field located lower left. A plurality of slits **163** extending in a direction at an angle of approximately 45 degrees to the X axis are formed in a fourth field located lower right.

Underneath the sub picture element electrodes **162a** and **162b**, a control electrode **161a** is formed along a center line of each of the picture elements, the center line being in parallel with the Y axis. This control electrode **161a** is electrically connected with the drain electrode **118a** of each of the TFTs **118**.

In addition, underneath each of the sub picture element electrodes **162a**, an auxiliary capacitance bus line **113** and an auxiliary capacitance electrode **161b** are formed along a center line of the sub picture element electrode **162a**, the center line being in parallel with the X axis. The auxiliary capacitance bus line **113** is formed in the same layer as a gate bus line **112** is. In addition, the auxiliary capacitance electrode **161b** is formed in the same layer as the control electrode **161a** is, and is electrically connected with the control electrode **161a**. A first insulating film (an equivalent to the insulating film **114** in FIG. 4) is formed between the auxiliary capacitance bus line **113** and the auxiliary capacitance electrode **161b**. An auxiliary capacitance is constituted of the auxiliary capacitance bus line **113**, the auxiliary capacitance electrode **161b** and the first insulating film therebetween. Furthermore, the auxiliary capacitance electrode **161b** is electrically connected with the sub picture element electrode **162a** through a contact hole **164**, which has been formed in a second insulating film (an equivalent to the insulating film **120** in FIG. 4).

Moreover, underneath the extremity of each of the sub picture element electrodes **162b**, a control electrode **161c** is formed. This control electrode **161c** also is formed in the same layer as the control electrode **161a** is, and is electrically connected with the control electrode **161a**. The control electrode **161c** is capacitively coupled to the sub picture element electrode **162b** through the second insulating film.

The structure of an opposing substrate according to this embodiment is also basically the same as that according to the first embodiment, and descriptions will be omitted for the structure according to this embodiment here. In addition, in the case of this embodiment, too, a polymer component such as diacrylate is added to liquid crystal, and the liquid crystal is filled into the space between a TFT substrate and the opposing substrate. Voltage is applied between a picture element electrode (each of the sub picture element electrodes **162a** and **162b**) and a common electrode. Thereby, liquid crystal molecules are aligned in predetermined directions. Thereafter, beams of ultraviolet light are irradiated to the polymer component. Accordingly, the polymer component is polymerized.

In the case of the second embodiment (see FIG. 6) which has been described, the liquid crystal molecules between the sub picture element electrodes **152a** and **152b** tilt in the direction in parallel with the X axis when voltage is applied. This causes a dark line between the sub picture element electrodes **152a** and **152b**. By contrast, in the case of this embodiment, the gap between the two sub picture element electrodes **162a** and **162b** extends in the same direction as the slits **163** adjacent to the gap do. This causes the liquid crystal molecules between the sub picture element electrodes **162a** and **162b** to tilt in the same direction as the slits **163** extend, when voltage is applied. Accordingly, a dark line does not appear between

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the sub picture element electrodes **162a** and **162b**. Thus, the substantial aperture ratio is improved.

Furthermore, in the case of this embodiment, too, a single picture element is provided with two types of fields which are different in transmittance-applied voltage characteristics, in common with the case of the first embodiment. This brings about an effect of avoiding deterioration in the display quality which would otherwise be caused when the screen is viewed in an oblique direction.

#### Fourth Embodiment

FIG. 8 is a plan view showing a liquid crystal display device according to a fourth embodiment of the present invention.

In the case of this embodiment, as shown in FIG. 8, each data bus line **177** is formed so as to be shaped like a zigzag, which causes an upper half of the data bus line in each picture element to extend in a direction at an angle of 45 degrees to the X axis, and a lower half of the data bus line in the picture element to extend in a direction at an angle of 315 degrees to the X axis. However, each gate bus line **122** is formed so as to be in parallel with the X axis, in common with the first to the third embodiments.

Three sub picture element electrodes **172a**, **172b** and **172c** as well as a TFT **118** are formed in each of the picture element regions to be defined by the gate bus lines **122** and the data bus lines **177**. In the case of this embodiment, too, a part of the gate bus line **122** is used as a gate electrode for a TFT **118**. A drain electrode **118b** and a source electrode **118a** are formed so as to be opposite to each other with the gate bus line **122** interposed therebetween. In each of the picture element regions, a control electrode **171** bent along the center line of the picture element region is formed underneath the sub picture element electrodes **172a** to **172c**. This control electrode **171** is formed on a first insulating film (an equivalent to the insulating film **114** in FIG. 3), and is electrically connected with the drain electrode **118b** of the TFT **118**.

The sub picture element electrode **172a** (a capacitively-coupled picture element electrode) is divided into two fields (domain control fields) by the center line. In addition, the right field is provided with slits **173** extending in a direction at an angle of approximately 315 degrees to the X axis. The left field is provided with slits **173** extending in a direction at an angle of approximately 135 degrees.

The sub picture element electrode **172b** (a directly-connected picture element electrode) is arranged in a center portion where each of the picture elements is bent. The sub picture element electrode **172b** is divided into four fields. Slits **173** extending in a direction at an angle of approximately 45 degrees to the X axis are formed in a first field. Slits **173** extending in a direction at an angle of approximately 135 degrees to the X axis are formed in a second field. Slits **173** extending in a direction at an angle of approximately 225 degrees to the X axis are formed in a third field. Slits **173** extending in a direction at an angle of approximately 315 degrees to the X axis are formed in a fourth field. This sub picture element electrode **172b** is electrically connected with the control electrode **171** through a contact hole **174** which is provided into a second insulating film (an equivalent to the insulating film **120** in FIG. 3).

The sub picture element electrode **172c** (a capacitively-coupled picture element electrode) is divided into two fields (domain control fields) by the center line. In addition, the right field is provided with slits **173** extending in a direction at an angle of approximately 45 degrees to the X axis. The left field is provided with slits **173** extending in a direction at an

angle of approximately 225 degrees. Each of the sub picture element electrodes **172a** and **172c** is connected with the control electrode **171** through the second insulating film.

The structure of an opposing substrate according to this embodiment is also basically the same as that according to the first embodiment, and descriptions will be omitted for the structure according to this embodiment here. In the case of this embodiment, too, a polymer component such as diacrylate is added to liquid crystal, and the liquid crystal is filled into the space between a TFT substrate and the opposing substrate. Voltage is applied between a picture element electrode (each of the sub picture element electrodes **172a** to **172c**) and a common electrode. Thereby, liquid crystal molecules are aligned in predetermined directions. Thereafter, beams of ultraviolet light are irradiated to the polymer component. Accordingly, the polymer component is polymerized.

In the cases of the first to the third embodiments, slits of each of the sub picture element electrodes extend in directions respectively at angles of 45 degrees, 135 degrees, 225 degrees and 315 degrees to the X axis. Accordingly, the liquid crystal molecules tilt in the same directions as the slits extend. However, a line of electric force occurs outwards in the extremity of each of the sub picture element electrodes. This causes the liquid crystal molecules between each of the sub picture element electrodes and the data bus line to tilt in a direction in parallel with the X axis. On the other hand, with regard to one of two polarizing plates, between which the liquid crystal panel is interposed, its absorption axis is arranged in parallel with the X axis. With regard to the other of the two polarizing plates, its absorption axis is arranged in parallel with the Y axis. In this case, dark parts occur between each of the sub picture element electrodes and the data bus line in each of the picture elements in the liquid crystal display device according to any one of the first to the third embodiments. This reduces the substantial aperture ratio.

With this taken into consideration, in the case of this embodiment, the data bus line **177** is beforehand designed to extend in directions at angles of 45 degrees and 315 degrees to the gate bus line **122** in each of the picture elements, as shown in FIG. 8. This causes the liquid crystal molecules between the data bus line **177** and each of the sub picture element electrodes **172a** to **172c** to tilt in a direction at an angle of 45 degrees to the polarization axes of the polarizing plates. This prevents dark parts from occurring between the data bus line **177** and each of the sub picture element electrodes **172a** to **172c**. The substantial aperture ratio is improved in the case of this embodiment in comparison with the cases of the first to the third embodiments. This brings about an effect that enables further brighter display. When the transmittance of a liquid crystal display device according to this embodiment which had been actually manufactured was examined, it was proved that the transmittance was improved by approximately 5% in comparison with the liquid crystal display device with a structure as shown in FIG. 3.

In the case of the liquid crystal display device according to this embodiment, a single picture element is provided with the plurality of types of fields which are different from one another in transmittance-applied voltage characteristics. This brings about an effect of improving the display quality to be observed when the screen is viewed in an oblique direction.

#### Fifth Embodiment

FIG. 9 is a plan view showing a liquid crystal display device according to a fifth embodiment of the present invention. This embodiment is different from the fourth embodiment in that the shapes of the sub picture element electrodes

according to this embodiment are different from those of the sub picture element electrodes according to the fourth embodiment. Except for the shapes, however, this embodiment has the same configuration as that according to the fourth embodiment does. If components and equivalents in FIG. 9 were the same as, or similar to, those in FIG. 8, the components and equivalents in FIG. 9 are denoted by the same reference numerals and symbols as those in FIG. 8 are. Thus, detailed descriptions will be omitted for the same, or similar, components and equivalents in FIG. 9.

In the case of the liquid crystal display device according to the fourth embodiment as shown in FIG. 8, many slits **173** are provided into each of the sub picture element electrodes **172a** to **172c**. These slits **173** are formed by use of a photolithography process. In other words, an ITO film, which is made into each of the sub picture element electrodes **172a** to **172c**, is coated with photoresist. Thereafter, a stepper exposure process is performed on the ITO film, and then a development process is performed on the ITO film. Using remaining photoresist as a mask, the ITO film is etched. In this manner, the slits **173** are formed. However, each of the slits **173** is minute. This causes the widths of the respective slits to be nonuniform due to unevenness of the film thickness of the photoresist film and due to a slight difference (shot unevenness) in amount of being exposed during the stepper exposure process. It is likely that this affects the optical characteristics, and that the display quality is reduced accordingly.

With this taken into consideration, in the case of the fifth embodiment, slits **173** are formed only in extremities respectively of sub picture element electrodes **182a** and **182c** (corresponding to the sub picture element electrodes **172a** and **172b** according to the fourth embodiment) and in the bending portion of the sub picture element electrode **182b** (corresponding to the sub picture element electrode **172b**). In the case of the liquid crystal display device according to this embodiment, when a polymer component (a monomer) added to the liquid crystal is polymerized, it takes longer for the liquid crystal molecules to complete tilting in the predetermined directions after voltage is applied, in comparison with the liquid crystal display device according to the fourth embodiment. However, while the liquid crystal display device according to this embodiment is being in actual use, the directions in which the liquid crystal molecules are aligned are determined by the polymer included in the liquid crystal layer. For this reason, the liquid crystal display device according to this embodiment can obtain response characteristics equal to those of the liquid crystal display device according to the fourth embodiment.

#### Sixth Embodiment

Hereinbelow, descriptions will be provided for a sixth embodiment of the present invention.

In the case of the liquid crystal display device as shown in FIG. 1, the widths respectively of the slits are caused to be nonuniform due to a photolithography process, as described above. Accordingly, in some cases, patterns shaped like a tile are seen when a display is performed in middle gray-scale. The applicants of the present invention have carried out various experiments and studies in order to solve such a problem. As a result of them, the applicants have found that the display unevenness due to the photolithography process can be prevented from occurring if values denoted by d, L and S are set in a way that they satisfy an equation in the form

$$L+d-S \geq 4 \mu\text{m}$$

(1)

where  $d$  denotes a thickness (a cell gap) of the liquid crystal layer;  $L$ , a width of conductive material portion (i.e. a microelectrode part) between two neighboring slits; and  $S$ , a width of the slit.

For example, the thickness  $d$  of the liquid crystal layer may be  $4\text{ }\mu\text{m}$ , concurrently the width  $L$  of the microelectrode part may be  $6\text{ }\mu\text{m}$ , and simultaneously the width  $S$  of the slit may be  $3.5\text{ }\mu\text{m}$ .

When a liquid crystal display device was actually manufactured with the aforementioned conditions, it was proved that tile-shaped patterns which would otherwise occur were able to be prevented. However, a new problem occurred which reduced brightness while a white display was being performed. It is conceivable that this problem came from the following reasons.

When voltage is applied between a picture element electrode and a common electrode, the liquid crystal molecules (liquid crystal molecules with negative dielectric anisotropy) tend to tilt in a direction orthogonal to a line of electric force stemming from the picture element electrode. As shown in FIG. 10, no sooner is voltage applied than the liquid crystal molecules **203** around the extremities (near a data bus line **202**) respectively of microelectrode parts **201** tilt towards the center of each of the picture elements. Over each slits **204** and each microelectrode part **201**, the respective liquid crystal molecules **203**, which are going to tilt in directions which are opposite to each other, collide with one another. Eventually, these liquid crystal molecules **203** tilt in the same direction as the slits **204** extend, under an influence of the liquid crystal molecule **203** around the extremities respectively of the microelectrode parts **201**.

However, liquid crystal molecules **203** between the data bus line **202** and each of the extremities of the respective microelectrode parts **201** tilt in a direction approximately perpendicular to the data bus line **202** when voltage is applied. This causes dark parts in this portion. If the widths respectively of the microelectrode parts **201** are made larger (for example, set at  $6\text{ }\mu\text{m}$ ), this increases a dark area, and accordingly reducing the brightness.

It is conceivable that, for the purpose of making the dark area smaller, each of the microelectrode parts **201** are stretched so that the interval between the microelectrode part **201** and the data bus line **202** is made narrower. However, mere reduction in the interval between the microelectrode part **201** and the data bus line **202** would result in increasing a parasitic capacitance between the microelectrode part **201** and the data bus line **202**, thus causing a crosstalk. This leads to deterioration in the display quality. In other words, improvement in the brightness and check of the crosstalk are in a tradeoff relationship.

The applicants of the present invention closely observed the alignment state of the liquid crystal molecules in the liquid crystal display device including the picture element electrode with the shape as shown in FIG. 10. As a result of this observation, it was found that the liquid crystal molecules **203** tilt in a direction approximately perpendicular to the data bus line **202** in a part in the extremity of each of the microelectrode parts **201** (a part indicated by reference symbol A in FIG. 10) which has no portion opposite to its neighboring microelectrode part **201**. The extremity of each of the microelectrode parts **201** is a factor in increasing the parasitic capacitance due to its vicinity to the data bus line **202**.

With this taken into consideration, in the case of this embodiment, an interval between the data bus line **212** and each of the microelectrode parts **215b** is made narrower, and concurrently a notch is provided in a part which constitutes the extremity of each of the microelectrode parts **215b**, and

which does not make a contribution to aligning the liquid crystal molecules in the same direction as each of the slits **215a** extends, as shown in FIG. 11. In other words, a notch is provided in a part of the microelectrode part (a part encompassed by a circle in FIG. 11) which has no portion opposite to its neighboring microelectrode part. This avoids increasing the parasitic capacitance. This can improve the transmittance to be observed while a white display is being performed, and can save the power consumption. In addition, this avoids deteriorating the display quality.

It should be noted that reference numeral **211** denotes a gate bus line; **212**, the data bus line; **214**, a TFT; and **215**, a picture element electrode. In addition, a dot-dashed line in the enlarged view of FIG. 11 denotes positions respectively of the extremities of the microelectrode parts of the conventional MVA mode liquid crystal display device.

It is very difficult to form microelectrode parts, in which extremities have an acute angle, by use of a photolithography process. Usually, the extremities respectively of the microelectrode parts are round. In addition, the roundness varies from one extremity to another due to a slight change in a condition under which a photolithography process is performed. This is a cause for making the optical characteristics nonuniform. For this reason, it is preferable that the extremities respectively of the microelectrode parts be shaped like an arc with a predetermined curvature, or like a polygon, when it is designed.

The applicants of the present invention further closely observed the alignment state of the liquid crystal molecules in the liquid crystal display device whose picture element electrodes have the shape as shown in FIG. 10. As a result of this observation, it was found that the liquid crystal molecules **203** did not tilt in a direction at an angle of 45 degrees in the vicinity of the base end of each of the slits **204** (a part indicated by reference symbol B in FIG. 10), and that this was a cause for decreasing a degree of white brightness. It is conceivable that this stemmed from the following reason.

The stem part of each of the picture element electrode (a part connecting the microelectrode parts with one another: in other words, a connection electrode **205**) is formed so as to be in parallel with the gate bus line **202**. With regard to liquid crystal molecules **203** in an area B surrounded by this connection electrode **205** and the microelectrode part **201**, some of the liquid crystal molecules **203** are going to tilt in a direction orthogonal to a line of electric force stemming from the connection electrode **205**, and the others are going to tilt in a direction orthogonal to a line of electric force stemming from the microelectrode part **201**. As a result, the two groups of the liquid crystal molecules **203** collide with each other. Eventually, the two groups tilt in a direction which keeps a balance between the two groups, or in a direction of a line which bisects an angle between the connection electrode **205** and the microelectrode part **201**. This direction deviates from the direction in which each of the slits **204** extends. This decreases the transmittance while a white display is being performed.

With this taken into consideration, in the case of this embodiment, the base end of each of the slits is designed to have a shape which is symmetrical along the center line of the slit. Specifically, for example, as shown in FIG. 12, the base end of each of the slits **215a** is designed to have a shape in which the two angles at the bottom of the base end are 90 degrees. Otherwise, for example, as shown in FIG. 13, the base end is designed to be shaped like an isosceles triangle. These shapes cause the liquid crystal molecules **203** around

the base end of each of the slits **215a** to tilt in the same direction as the center line of the slit **215a** extends. This improves the brightness.

Hereinbelow, descriptions will be provided for a result of examining characteristics respectively of the liquid crystal display devices according to examples of this embodiment which have been actually manufactured while comparing with comparative examples. It should be noted that, each of the liquid crystal display devices respectively according to the examples and the comparative examples has an opposing substrate with the same structure as that of the opposing substrate of the liquid crystal display device according to the first embodiment. In addition, diacrylate is added to the liquid crystal (liquid crystal with negative dielectric anisotropy). This liquid crystal is filled in the space between the TFT substrate and the opposing substrate. Thereafter, beams of ultraviolet light are irradiated to the diacrylate while predetermined voltage is being applied between the picture element electrode and the common electrode. A polymer is formed in the liquid crystal layer in this manner. In addition, polarizing plates are arranged respectively on the two sides of the liquid crystal panel.

#### First Comparative Example

A liquid crystal display device having picture element electrodes as shown in FIG. 1 was manufactured. In the case of the liquid crystal display device according to the first comparative example, the thickness  $d$  of the liquid crystal layer was  $3.4\text{ }\mu\text{m}$ , the width  $L$  of each of the microelectrode parts was  $3\text{ }\mu\text{m}$ , and the width  $S$  of each of the slits was  $3.4\text{ }\mu\text{m}$ . In this occasion,  $L+d-S$  took on  $3.4\text{ }\mu\text{m}$ , and did not satisfy the equation (1). When a display was performed with middle gray-scale on the entire surface of the liquid crystal display device according to the first comparative example, tile-shaped patterns were observed.

#### Second Comparative Example

A liquid crystal display device having picture element electrodes as shown in FIG. 1 was manufactured. In the case of the liquid crystal display device according to the second comparative example, the thickness  $d$  of the liquid crystal layer was  $4\text{ }\mu\text{m}$ , the width  $L$  of each of the microelectrode parts was  $3\text{ }\mu\text{m}$ , and the width  $S$  of each of the slits was  $3.4\text{ }\mu\text{m}$ . In this occasion,  $L+d-S$  took on  $3.4\text{ }\mu\text{m}$ , and did not satisfy the equation (1). When a display was performed with middle gray-scale on the entire surface of the liquid crystal display device according to the second comparative example, tile-shaped patterns were observed.

#### Third Comparative Example

A liquid crystal display device having picture element electrodes as shown in FIG. 1 was manufactured. In the case of the liquid crystal display device according to the third comparative example, the thickness  $d$  of the liquid crystal layer was  $4\text{ }\mu\text{m}$ , the width  $L$  of each of the microelectrode parts was  $6\text{ }\mu\text{m}$ , and the width  $S$  of each of the slits was  $3.5\text{ }\mu\text{m}$ . In this occasion,  $L+d-S$  took on  $6.5\text{ }\mu\text{m}$ , and satisfied the equation (1). When a display was performed with middle gray-scale on the entire surface of the liquid crystal display device according to the third comparative example, no tile-shaped pattern was observed. However, when the brightness was measured while a white display was being performed on this liquid crystal display device, it was found that the brightness

decreased by approximately 10% in comparison with the liquid crystal display device according to the second comparative example.

#### First Example

A liquid crystal display device having picture element electrodes as shown in FIG. 11 was manufactured. In the case of the liquid crystal display device according to the first example, the thickness  $d$  of the liquid crystal layer was  $4\text{ }\mu\text{m}$ , the width  $L$  of each of the microelectrode parts was  $6\text{ }\mu\text{m}$ , and the width  $S$  of each of the slits was  $3\text{ }\mu\text{m}$ . In this occasion,  $L+d-S$  took on  $7\text{ }\mu\text{m}$ , and satisfied the equation (1). When a display was performed with middle gray-scale on the entire surface of the liquid crystal display device according to the first example, no tile-shaped pattern was observed. In addition, when the brightness was measured while a white display was being performed on this liquid crystal display device, it was found that the brightness was improved by approximately 7% in comparison with the liquid crystal display device according to the third comparative example.

#### Second Example

A liquid crystal display device having picture element electrodes as shown in FIG. 12 was manufactured. In the case of the liquid crystal display device according to the second example, the thickness  $d$  of the liquid crystal layer was  $4\text{ }\mu\text{m}$ , the width  $L$  of each of the microelectrode parts was  $6\text{ }\mu\text{m}$ , and the width  $S$  of each of the slits was  $3\text{ }\mu\text{m}$ . In this occasion,  $L+d-S$  took on  $7\text{ }\mu\text{m}$ , and satisfied the equation (1). When a display was performed with middle gray-scale on the entire surface of the liquid crystal display device according to the second example, no tile-shaped pattern was observed. In addition, when the brightness was measured while a white display was being performed on this liquid crystal display device, it was found that the brightness was improved by approximately 7.1% in comparison with the liquid crystal display device according to the third comparative example.

#### Third Example

A liquid crystal display device having picture element electrodes as shown in FIG. 13 was manufactured. In the case of the liquid crystal display device according to the third example, the thickness  $d$  of the liquid crystal layer was  $4\text{ }\mu\text{m}$ , the width  $L$  of each of the microelectrode parts was  $6\text{ }\mu\text{m}$ , and the width  $S$  of each of the slits was  $3\text{ }\mu\text{m}$ . In this occasion,  $L+d-S$  took on  $7\text{ }\mu\text{m}$ , and satisfied the equation (1). When a display was performed with middle gray-scale on the entire surface of the liquid crystal display device according to the third example, no tile-shaped pattern was observed. In addition, when the brightness was measured while a white display was being performed on this liquid crystal display device, the brightness was improved by approximately 7.1% in comparison with the liquid crystal display device according to the third comparative example.

Through comparison of the first to the third examples with the first to the third comparative examples, it was confirmed that the liquid crystal display devices according to this embodiment were effective for improving the display quality, and that the transmittance to be observed while a white display was being performed was so high that the liquid crystal display device was effective in saving power consumption.

#### Seventh Embodiment

Hereinafter, descriptions will be provided for a seventh embodiment of the present invention.

In the case of the liquid crystal display device according to the first embodiment, the aperture ratio can be made larger, since the liquid crystal display device does not include structural components such as protrusions and wide slits. If, however, the auxiliary capacitance were not sufficiently large relative to the picture element capacitance, voltage to be applied to the liquid crystal decreases to a large extent in a frame period (approximately 16.7 ms). Accordingly, the transmittance intensity is saturated before it reaches its peak. This is a phenomenon which is termed as a two-step response. In a case where the transmission intensity is saturated while it is less than or equal to 90% due to a two-step response, even if the liquid crystal were caused to rise sharply, a speed at which the liquid crystal panel responds can not be increased. With this taken into consideration, in the case of this embodiment, a capacitance value of the auxiliary capacitance is intended to be increased while the aperture ratio is being maintained, thereby solving the aforementioned problems. Specific descriptions will be provided for the present invention with reference to FIGS. 14 and 15.

FIG. 14 is a plan view showing one picture element in a liquid crystal display device according to the seventh embodiment of the present invention. FIG. 15 is a cross-sectional view taken along the I-I line in FIG. 14. Incidentally, an illustration of a polarizing plate is omitted in FIG. 14.

On a TFT substrate 310, a plurality of gate bus lines 312 extending in the horizontal direction (X-axis direction) and a plurality of data bus lines 317 extending in the perpendicular direction (Y-axis direction) are formed as shown in FIG. 14. Picture element regions are defined by the gate bus lines 312 and the data bus lines 317, and are shaped like a rectangle. In the center of each of the picture element regions, an auxiliary capacitance bus line 313 is formed so as to be in parallel with the gate bus line 312.

In each of the picture element regions, auxiliary capacitance lower electrodes 313a and 313c, a TFT 318, an auxiliary capacitance electrode 319b, control electrodes 319a and 319c, and a first to a third sub picture element electrodes 321a to 321c are formed. The auxiliary capacitance lower electrodes 313a and 313c are formed so as to be in parallel with a center line of the picture element region, the center line being in parallel with the Y axis. The auxiliary capacitance lower electrodes 313a and 313c are electrically connected with the auxiliary capacitance bus line 313.

With regard to the TFT 318, a part of the gate bus line 312 is used as the gate electrode. A drain electrode 318a and a source electrode 318b are arranged to be opposed to each other with the gate bus line 312 interposed therebetween.

The control electrodes 319a and 319c are formed in positions respectively opposite to the auxiliary capacitance lower electrodes 313a and 313c with a first insulating film 314 interposed therebetween. The control electrodes 319a and 319c are electrically connected with the drain electrode 318a. In addition, the auxiliary capacitance electrode 319b is formed so as to be opposite to the auxiliary capacitance bus line 313 with the first insulating film 314 interposed therebetween. The auxiliary capacitance electrode 319b is electrically connected with the control electrodes 319a and 319c. An auxiliary capacitance is constituted of: a group consisting of the auxiliary capacitance bus line 313 as well as the auxiliary capacitance lower electrodes 313a and 313c; a group consisting of the auxiliary capacitance electrode 319b as well as the control electrodes 319a and 319c; and the first insulating film 314 between the two groups.

The sub picture element electrodes 321a to 321c are formed of a transparent conductive material such as ITO, and are arranged, on a second insulating film 320, along the data

bus line 317. As shown in FIG. 14, the sub picture element electrode 321a (capacitively-coupled picture element electrode) is arranged in a range upper in the Y axis direction of the picture element region, and is divided into two fields (domain control fields) with a center line in parallel with the Y axis defined as the boundary. In addition, slits 322 extending in a direction at an angle of 45 degrees to the X axis are formed in the right field. Slits 322 extending in a direction at an angle of 135 degrees to the X axis are formed in the left field. This sub picture element electrode 321a is capacitively coupled to the control electrode 319a through the second insulating film 320.

The sub picture element electrode 321b (directly-connected picture element electrode) is arranged in the center of the picture element region. The sub picture element electrode 321b is divided into four fields (domain control fields) with a center line in parallel with the X axis and with a center line in parallel with the Y axis defined as the boundaries. Slits 322 extending in a direction at an angle of 45 degrees to the X axis are formed in the upper right field. Slits 322 extending in a direction at an angle of 135 degrees to the X axis are formed in the upper left field. Slits 322 extending in a direction at an angle of 225 degrees to the X axis are formed in the lower left field. Slits 322 extending in a direction at an angle of 315 degrees to the X axis are formed in the lower right field. This sub picture element electrode 321b is electrically connected to the auxiliary capacitance electrode 319b through a contact hole 320a.

The sub picture element electrode 321c (capacitively-coupled picture element electrode) is arranged in a range lower in the Y axis direction of the picture element region, and is divided into two fields (domain control fields) with a center line in parallel with the Y axis defined as the boundary. In addition, slits 322 extending in a direction at an angle of 315 degrees to the X axis are formed in the right field. Slits 322 extending in a direction at an angle of 225 degrees to the X axis are formed in the left field. This sub picture element electrode 321c is capacitively coupled to the control electrode 319c through the second insulating film 320.

Hereinbelow, further detailed descriptions will be provided for structures respectively of the TFT substrate 310 and an opposing substrate 330 with reference to the plan view of FIG. 14 and the cross-sectional view of FIG. 15.

The gate bus line 312, the auxiliary capacitance bus line 313 and the auxiliary capacitance lower electrodes 313a and 313c are formed on a glass substrate 311 which constitutes the base of the TFT substrate 310. The gate bus line 312, the auxiliary capacitance bus line 313 and the auxiliary capacitance lower electrodes 313a and 313c are simultaneously formed through patterning a metallic film, into which, for example, Al and Ti are laminated, by use of a photolithography process.

The first insulating film (gate insulating film) 314, made of SiO<sub>2</sub>, SiN or the like, is formed over the gate bus line 312, the auxiliary capacitance bus line 313, as well as the auxiliary capacitance lower electrodes 313a and 313c. A semiconductor film (amorphous silicon or polysilicon film) 315, which constitutes an active layer of the TFT 318, is formed in a predetermined area in the first insulating film 314. A channel protecting film 316 made of SiN or the like is formed on the semiconductor film 315. The drain electrode 318a and the source electrode 318b of the TFT 318 are formed respectively on the two sides of the channel protecting film 316.

The data bus line 317 and the auxiliary capacitance electrode 319b as well as the control electrodes 319a and 319c are formed on the first insulating film 314. The data bus line 317 is connected to the source electrode 318b of the TFT 318. The

control electrodes **319a** and **319c** are connected to the drain electrode **318a** of the TFT **318**. As shown in FIG. 15, the auxiliary capacitance electrode **319b** is formed in a position opposite to the auxiliary capacitance bus line **313** with the first insulating film **314** interposed therebetween. The control electrode **319a** is formed in a position opposite to the auxiliary capacitance lower electrode **313a** with the first insulating film **314** interposed therebetween. The control electrode **319c** is formed in a position opposite to the auxiliary capacitance lower electrode **313c** with the first insulating film **314** interposed therebetween.

The data bus line **317**, the drain electrode **318a**, the source electrode **318b** and the auxiliary capacitance electrode **319b** as well as the control electrodes **319a** and **319c** are simultaneously formed through patterning a metallic film, into which, for example, Ti, Al and Ti are laminated, by use of a photolithography process.

The second insulating film **320** made, for example, of SiN is formed over the data bus line **317**, the drain electrode **318a**, the source electrode **318b** and the auxiliary capacitance electrode **319b** as well as the control electrodes **319a** and **319c**. The sub picture element electrodes **321a** to **321c** are formed on the second insulating film **320**. As described above, the sub picture element electrodes **321a** to **321c** are respectively provided with the slits **322** extending in the respective directions oblique to the X axis. In the case of this embodiment, the width of each of the slits **322** provided to the sub picture element electrodes **321a** to **321c** is 3.5  $\mu\text{m}$ , and the width of a conductive material portion (microelectrode part) between each two neighboring slits **322** is 6  $\mu\text{m}$ .

The sub picture element electrode **321a** is capacitively coupled to the control electrode **319a** through the second insulating film **320**. The sub picture element electrode **321b** is electrically connected to the auxiliary capacitance electrode **319b** through the contact hole **320a**, which has been formed in the second insulating film **320**. The sub picture element electrode **321c** is capacitively coupled to the control electrode **319c** through the second insulating film **320**.

A vertical alignment film (not illustrated) made of polyimide or the like is formed on the sub picture element electrodes **321a** to **321c**.

On the other hand, black matrices **332**, color filters **333** and a common electrode **334** are formed on a glass substrate **331** (underneath the glass substrate **331** in FIG. 15) which constitutes the base of the opposing substrate **330**.

The black matrix **332** is made, for example, of black resin or a metal such as Cr, and is arranged in a position opposite to the gate bus line **312**, the data bus line **317**, the auxiliary capacitance bus line **313** and the TFT **318** on the TFT substrate **310**. Color filters **333** are classified into three types, such as red, green and blue. A color filter with any one of the three colors is arranged in each of the picture element regions.

The common electrode **334** is formed of a transparent conductive material such as ITO, and is arranged on the color filter **333** (on the lower side of the color filter **333** in FIG. 15). A vertical alignment film (not illustrated) made of polyimide or the like is formed on the common electrode **334** (on the lower side of the common electrode **334** in FIG. 15).

A liquid crystal layer **340** is arranged between the TFT substrate **310** and the opposing substrate **330**. The liquid crystal layer **340** is made of liquid crystal with negative dielectric anisotropy which is contained between the TFT substrate **310** and the opposing substrate **330**. A polymer is formed in the liquid crystal layer **340**, the polymer determining directions in which liquid crystal molecules are aligned when voltage is applied. This polymer is formed in the following process. A polymer component (a monomer such as

diacrylate) is added to the liquid crystal. Then, beams of ultraviolet light are irradiated to the polymer component while voltage is applied between the common electrode **334** and each of the sub picture element electrodes **321a** to **321c**. Thereby, the polymer component is polymerized into the polymer.

It should be noted that, in the case of this embodiment, the liquid crystal with negative dielectric anisotropy is used. If liquid crystal with positive dielectric anisotropy were used instead, the liquid crystal molecules are aligned in parallel with the surfaces respectively of the substrates while no voltage is being applied. This hinders applied voltage from being made larger when the polymer component is intended to be polymerized. Accordingly, this makes it difficult for the alignment directions of the liquid crystal molecules to match the directions in which the slits extend.

In the case of this embodiment, the auxiliary capacitance lower electrodes **313a** and **313c** as well as the control electrodes **319a** and **319c** are arranged in an area along a boundary between neighboring domain control fields which are different from each other in alignment direction of liquid crystal molecules, or in an area where light is not transmitted. This arrangement enables the auxiliary capacitance to be made larger without decreasing the aperture ratio. On the contrary, the widths respectively of the auxiliary capacitance bus line **313** and the auxiliary capacitance electrode **319b** may be made smaller in response to the capacitance constituted of the auxiliary capacitance lower electrodes **313a** and **313c** as well as the control electrodes **319a** and **319c**. In this case, the aperture ratio can be increased while the capacitance value of the auxiliary capacitance is being maintained.

FIG. 16 is a diagram showing a relationship between a picture element capacitance ratio (a ratio of the auxiliary capacitance to the picture element capacitance) and a voltage ratio with the picture element capacitance ratio and the voltage ratio represented respectively by the horizontal axis and the vertical axis. Note that, in this case, 4  $\mu\text{m}$  is the thickness (cell gap) of the liquid crystal layer; 0.33  $\mu\text{m}$  is the thickness of the first insulating film between a group of the auxiliary capacitance bus line and the auxiliary capacitance lower electrodes and a group of the auxiliary capacitance electrode and the control electrodes;  $-3.5$  is a variation  $\Delta\epsilon$  in conductivity of the liquid crystal; and 53% is the aperture ratio. In addition, the voltage ratio represents a ratio of a write-in voltage during a white display to voltage which is applied to the liquid crystal layer. The write-in voltage during the white display is set at 1.

In this case, with regard to the auxiliary capacitance of the liquid crystal display device according to the first embodiment as shown in FIG. 3, its picture element capacitance ratio was 1.5. On the other hand, with regard to the auxiliary capacitance of the liquid crystal display device according to this embodiment, its picture element capacitance ratio was 2.5. With regard to the liquid crystal display device according to the first embodiment, when the picture element capacitance ratio was converted to a ratio of voltage to be applied to the liquid crystal, the voltage ratio was 0.92. With regard to the liquid crystal display device according to this embodiment, when the picture element capacitance ratio was converted to a ratio of voltage to be applied to the liquid crystal, the voltage ratio was 0.94. It has been already found that, in a case where the voltage ratio became smaller than a voltage ratio which caused the transmission intensity to measure 90%, even if the liquid crystal molecules rose sharply, the response speed of the liquid crystal panel did not increase. The voltage ratio which caused the transmission intensity to measure 90% affected not only the optical characteristics of the liquid crystal but also the alignment uniformity of the liquid crystal

molecules. In each of the cases of the liquid crystal display devices according to the first and the seventh embodiments, its respective voltage ratio which caused the transmission intensity to measure 90% was 0.93. It has been learned through these that the liquid crystal display device according to this embodiment had preferable response characteristics.

The liquid crystal display device according to the first embodiment and the liquid crystal display device according to this embodiment were actually manufactured, and their respective response speeds were measured. In other words, for each of the two liquid crystal display devices, a rise time ( $\tau_r$ ) in which the transmission intensity rose from 10% to 90% was measured, and a fall time ( $\tau_f$ ) in which the transmission intensity fell from 90% to 10% was measured. Then, a response speed defined by summation of the rise time and the fall time was measured. As a result of the measurements, it was proved that a response speed of the liquid crystal display device according to the first embodiment was 20 ms whereas a response speed of the liquid crystal display device according to this embodiment was as short as 12 ms.

#### Eighth Embodiment

Hereinbelow, descriptions will be provided for an eighth embodiment of the present invention.

In the case of the aforementioned liquid crystal display device according to the seventh embodiment, the voltage which is applied to the sub picture element electrode **321b** directly connected to the TFT **318** is different from the voltage which is applied to the sub picture element electrodes **321a** and **321c** connected to the TFT **318** though capacitive coupling. This causes electric potential difference between the sub picture element electrode **321b** and each of the sub picture element electrodes **321a** and **321c**. This electric potential difference causes the alignment direction of the liquid crystal molecules between the sub picture element electrode **321b** and the sub picture element electrode **321a** as well as the alignment direction of the liquid crystal molecules between the sub picture element electrode **321b** and the sub picture element electrode **321c** to deviate respectively from the directions in which the slits **322** extend. A phenomenon of this kind is termed as an azimuth deviation (or a  $\phi$  deviation). If the azimuth deviation occurred, the birefringence of the liquid crystal decreases locally. This causes a dark line to occur. This is a cause for decreasing the light transmittance.

FIG. **17** is a diagram showing transmittance characteristics and alignment characteristics in the case of the liquid crystal display device according to the seventh embodiment. In FIG. **17**, reference numeral **2** denotes an auxiliary capacitance lower electrode (corresponding to the auxiliary capacitance lower electrodes **313a** and **313c** in FIG. **14**); **4**, a control electrode (corresponding to the control electrodes **319a** and **319c** in FIG. **14**); **1**, a sub picture element electrode connected to the TFT (corresponding to the sub picture element electrode **321b** in FIG. **14**); and **3**, a sub picture element electrode capacitively coupled to the control electrode **4** (corresponding to the sub picture element electrodes **321a** and **321c** in FIG. **14**).

As shown in FIG. **17**, an electric potential difference occurs between the sub picture element electrodes **1** and **3**. This causes a phenomenon (an azimuth deviation) where the alignment directions of liquid crystal molecules deviate from the directions in which the slits extend. In addition, portions where the respective azimuth deviations occur turn into dark lines since the birefringence of the liquid crystal decreases in each of the portions. In the case of the liquid crystal display device according to the seventh embodiment, as indicated by

reference numeral **9** in FIG. **17**, dark lines occur respectively on the two sides (portions encompassed respectively by dashed lines in the right diagram in FIG. **17**) of the micro-electrode part in an edge of the sub picture element electrode **3** (a microelectrode part which is the closest to the sub picture element electrode **1**).

With this taken into consideration, in the case of this embodiment, the dark lines are inhibited from occurring between the sub picture element electrode directly connected to the TFT and each of the sub picture element electrodes capacitively coupled to the TFT. This enables the substantial aperture ratio to be improved. Hereinbelow, specific descriptions will be provided for this embodiment with reference to FIG. **18**.

FIG. **18** is a plan view showing a picture element in a liquid crystal display device according to the eighth embodiment of the present invention. Incidentally, if components and equivalents in FIG. **18** were the same as, or similar to, those in FIG. **14**, the components and equivalents in FIG. **18** are denoted by the same reference numerals and symbols as those in FIG. **14** are. Thus, detailed descriptions will be omitted for the same, or similar, components and equivalents in FIG. **18**.

In the case of this embodiment, a group of an auxiliary capacitance lower electrode **341** and a control electrode **345** is arranged under an area between a sub picture element electrode **321b** directly connected to a TFT **318** and a sub picture element electrode **321a** capacitively coupled to a control electrode **319a**. The other group of an auxiliary capacitance lower electrode **341** and a control electrode **345** is arranged under an area between the sub picture element electrode **321b** directly connected to the TFT **318** and a sub picture element electrode **321c** capacitively coupled to a control electrode **319c**. The auxiliary capacitance lower electrode **341** is formed so as to be in parallel with each of the slits **322** in the vicinity of the auxiliary capacitance lower electrode **341**, and is connected to auxiliary capacitance lower electrodes **313a** and **313c**. In addition, the control electrodes **345** are formed in the respective positions opposite to the auxiliary capacitance lower electrodes **341** with a first insulating film interposed therebetween, and are connected respectively to the control electrodes **319a** and **319c**.

As described above, in the case of the liquid crystal display device according to this embodiment, one control electrode **345**, whose voltage is equal to that of a drain electrode **318a** of the TFT **318**, is formed under the area between the sub picture element electrode **321b** and the sub picture element electrode **321a**. The other control electrode **345**, whose voltage is equal to that of the drain electrode **318a** of the TFT **318**, is formed under the area between the sub picture element electrode **321b** and the sub picture element electrode **321c**. Accordingly, one electric field in the horizontal direction occurs between the sub picture element electrode **321b** and the sub picture element electrode **321a**. The other electric field in the horizontal direction occurs between the sub picture element electrode **321b** and the sub picture element electrode **321c**. One electric field in oblique directions occurs between the sub picture element electrode **321a** and the control electrode **345**. The other electric field in oblique directions occurs between the sub picture element electrode **321c** and the control electrode **345**.

Electric field intensity (electric field density) is in proportion to an electric potential difference and a distance between electrodes. In accordance with this law, influence which each of the electric fields in the oblique directions has on the liquid crystal molecules is larger than influence which each of the electric fields in the horizontal direction has on the liquid crystal molecules, while the interval between the sub picture

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element electrode **321b** and each of the sub picture element electrodes **321a** and **321c** is 3.5  $\mu\text{m}$  (equal to the width of each of the slits **322**); and the thickness of the insulating film between the control electrode **345** and each of the sub picture element electrodes **321a** and **321c** is 0.33  $\mu\text{m}$ . Accordingly, only in one (the one side being opposite to the sub picture element electrode **321b**) of the two sides of microelectrode parts, which are the extremities of the sub picture element electrodes **321a** and **321c**, do dark lines occur. This improves the substantial aperture ratio.

FIG. **19** is a diagram showing transmittance characteristics and alignment characteristics in the case of the liquid crystal display device according to this embodiment. If components and equivalents in FIG. **19** were the same as those in FIG. **17**, the components and equivalents in FIG. **19** are denoted by the same reference numerals as those in FIG. **17** are. In the case of the liquid crystal display device according to this embodiment, only in one of the two sides of the microelectrode part (a side encompassed by a dashed line in FIG. **19**), which was an edge of the sub picture element electrode **3**, did a dark line occur, as shown in FIG. **19**. Through comparing FIG. **19** with FIG. **17**, it is learned that the liquid crystal display device according to this embodiment has an improved substantial aperture ratio in comparison with the liquid crystal display device as shown in FIG. **17**.

Furthermore, the liquid crystal display device according to this embodiment has larger auxiliary capacitance than that according to the seventh embodiment, since the auxiliary capacitance lower electrodes **341** are formed respectively under the control electrodes **345**. This brings about an advantage of further reducing the response time of the liquid crystal panel.

As shown in FIG. **20**, the widths respectively of the auxiliary capacitance bus line **313** and the auxiliary capacitance electrode **319b** may be made smaller in response to a capacitance constituted of the control electrodes **345** and the auxiliary capacitance lower electrode **341**. The smaller widths respectively of the auxiliary capacitance bus line **313** and the auxiliary capacitance electrode **319b** brings about another advantage of further improving the substantial aperture ratio.

In the case of the liquid crystal display device as shown in FIG. **18**, when the picture element capacitance ratio was converted into a ratio of voltage to be applied to liquid crystal, the voltage ratio was 0.96. In the case of the liquid crystal display device as shown in FIG. **20**, when the picture element capacitance ratio was converted into a ratio of voltage to be applied to liquid crystal, the voltage ratio was 0.94. In addition, the liquid crystal display devices respectively as shown in FIGS. **18** and **20** were actually manufactured, and their respective response speeds were measured. As a result of the measurement, 10 ms was the response speed of the liquid crystal display device as shown in FIG. **18**, and 12 ms was the response speed of the liquid crystal display device as shown in FIG. **20**.

#### Ninth Embodiment

FIG. **21** is a plan view showing a picture element of a liquid crystal display device according to a ninth embodiment of the present invention. If components and equivalents in FIG. **21** were the same as, or similar to, those in FIG. **18**, the components and equivalents in FIG. **21** are denoted by the same reference numerals and symbols as those in FIG. **18** are. Thus, detailed descriptions will be omitted for the same, or similar components and equivalents in FIG. **21**.

In the case of this embodiment, a sub picture element electrode **351a** is formed between a sub picture element elec-

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trode **321b** (a directly-connected picture element electrode) and a sub picture element electrode **321a** (a capacitively-coupled picture element electrode). A sub picture element electrode **351b** is formed between the sub picture element electrode **321b** (the directly-connected picture element electrode) and a sub picture element electrode **321c** (a capacitively-coupled picture element electrode). The sub picture element electrodes **351a** and **351b** are formed of ITO, in common with the sub picture element electrodes **321a** to **321c**. In addition, the sub picture element electrodes **351a** and **351b** extend in the same direction as microelectrode parts of the sub picture element electrodes **321a** to **321c** adjacent to the sub picture element electrodes **351a** and **351b** extend.

A group of an auxiliary capacitance lower electrode **341** and a control electrode **345** is formed in an area between the sub picture element electrode **351a** and the sub picture element electrode **321a**. The other group of an auxiliary capacitance lower electrode **341** and a control electrode **345** is formed in an area between the sub picture element electrode **351b** and the sub picture element electrode **321c**. In addition, the sub picture element electrode **351a** is capacitively coupled to control electrodes (control electrodes **319a** and **345**) through a second insulating film. The sub picture element electrode **351b** is capacitively coupled to control electrodes (control electrodes **319c** and **345**) through the second insulating film. In the case of this embodiment, a capacitance between a sub picture element electrode **351** and a corresponding control electrode is designed to be larger. Accordingly, voltage which is larger than that to be applied to the control electrode **321a** is applied to the sub picture element electrode **351a**. Voltage which is larger than that to be applied to the control electrode **321c** is applied to the sub picture element electrode **351b**. In other words, in the case of this embodiment, voltage applied to the control electrode **321b** is larger than voltage applied to the control electrodes **351a** and **351b**, which is larger than voltage applied to the control electrodes **321a** and **321c**.

As described above, in the case of this embodiment, an electric potential difference between neighboring sub picture element electrodes is smaller when the sub picture element electrode **351** is present than when the sub picture element electrode **351** is absent. This further inhibits a dark line from occurring due to an azimuth deviation.

FIG. **22** is a diagram showing transmittance characteristics in the case of the liquid crystal display device according to this embodiment. If components and equivalents in FIG. **22** were the same as those in FIG. **19**, the components in FIG. **22** are denoted by the same reference numerals as those in FIG. **19** are. Through comparing FIG. **22** and FIG. **19**, it is learned that the liquid crystal display device according to this embodiment has a further improved substantial aperture ratio than the liquid crystal display device as shown in FIG. **19**.

With regard to the liquid crystal display device according to this embodiment, when the picture element capacitance ratio was converted to a ratio of voltage to be applied to the liquid crystal, the voltage ratio was 0.94. In addition, the liquid crystal display device according to this embodiment was actually manufactured, and its response speed was measured. As a result of the measurement, the response speed was 12 ms.

#### Tenth Embodiment

Hereinbelow, descriptions will be provided for a tenth embodiment of the present invention.

In the case of the liquid crystal display device as shown in FIG. **1**, as described above, the alignment of the liquid crystal

molecules is put out of order in the base end and the extremity of each of the slits when voltage is applied. This is a cause of deteriorating the substantial aperture ratio. In addition, if each of the microelectrode parts were extended toward a position near the corresponding data bus line, the substantial aperture ratio can be improved.

FIGS. 23A and 24A are diagrams respectively showing a light transmission condition to be observed when voltage is applied in the case of a liquid crystal display device in which an interval between a microelectrode part and a data bus line is 7  $\mu\text{m}$ . FIGS. 23B and 24B are diagrams respectively showing a light transmission condition to be observed when voltage is applied in the case of a liquid crystal display device in which an interval between a microelectrode part and a data bus line is 5  $\mu\text{m}$ . FIGS. 23A and 23B are diagrams respectively showing a light transmission condition to be observed when voltage is applied in the case of a liquid crystal display device having no black matrices (BM). FIGS. 24A and 24B are diagrams respectively showing a light transmission condition to be observed when voltage is applied in the case of a liquid crystal display device having black matrices (BM). In each of the liquid crystal display devices, the width of its microelectrode part was 6  $\mu\text{m}$ , and the width of its slit was 3.4  $\mu\text{m}$ .

From each of FIGS. 23A and 23B, it was learned that a dark portion occurred due to alignment disorder of liquid crystal molecules in an end portion of the microelectrode part. In addition, through comparing FIG. 23A with FIG. 23B, it was learned that an area representing the dark portion was smaller when the interval between the microelectrode part and the data bus line was made small. In the case of an actual liquid crystal display device, a space between a microelectrode part and a corresponding data bus line is covered with a black matrix, as shown in FIGS. 24A and 24B. When brightness of the liquid crystal display device as shown in FIG. 24A was measured, it was 170  $\text{cd}/\text{m}^2$ . When brightness of the liquid crystal display device as shown in FIG. 24B was measured, it was 181  $\text{cd}/\text{m}^2$ .

If, as described above, each of the microelectrode parts were extended to a position near the data bus line, and a space between each of the microelectrode parts and the data bus line were covered with the black matrix, the substantial aperture ratio of the liquid crystal display device can be made larger, and the brightness of it can be improved. However, if an interval between each of the microelectrode parts and the data bus line were made further smaller, this causes deterioration in the display quality due to a crosstalk.

FIGS. 25A and 25B are diagrams respectively showing results of examining transition characteristics of two liquid crystal display devices from a time when voltages were applied to their respective liquid crystals till a time when alignment of their respective liquid crystals became stable by use of a high-speed camera. Incidentally, FIG. 25A shows transition characteristics of the liquid crystal display device with linear polarizing plates arranged respectively on the two sides of its liquid crystal panel. FIG. 25B shows transition characteristics of the liquid crystal display device with circular polarizing plates (a linear polarizing plate+ a  $\frac{1}{4}$  wavelength plate) arranged respectively on the two sides of its liquid crystal panel. In the case of each of the two liquid crystal display devices, the interval between each of the microelectrode parts and the data bus line was 7  $\mu\text{m}$ , the width of each of the microelectrode parts was 6  $\mu\text{m}$ , and the width of each of the slits was 3.5  $\mu\text{m}$ . In the case of a normal liquid crystal display device, 16.7 ms was one frame.

Through FIGS. 25A and 25B, it was learned that, if the circular polarizing plate were used, the brightness and the

response speed were able to be improved. However, the circular polarizing plate is expensive in comparison with the linear polarizing plate. In some cases, the circular polarizing plate may not be used depending on an intended use of the liquid crystal display device. From FIG. 25A, it was learned that it took longer time for liquid crystal molecules in the base end and the extremity of each of the slits to become stable in terms of their alignment.

With this taken into consideration, in the case of this embodiment, the brightness and the response characteristics of the liquid crystal display device is increased by improving the alignment of the liquid crystal molecules in the base end and the extremity of each slits of the picture element electrodes. Detailed descriptions will be provided for the liquid crystal display device according to this embodiment with reference to the below-mentioned examples 1 to 4.

It should be noted that, in the case of each of the following examples, if a film made of a dielectric material were formed so as to have the same shape as each of the slits does, the film may be used instead of the slit. The film made of the dielectric material can control the alignment direction of the liquid crystal molecules in the same manner as the slit can. Accordingly, the film can obtain the same effect as the slit does.

#### First Example

FIG. 26 is a plan view showing a picture element in a liquid crystal display device according to a first example of the tenth embodiment.

A gate bus line 412 extending in the horizontal direction (the X-axis direction) and a data bus line 417 extending in the vertical direction (the Y-axis direction) are formed in a TFT substrate. An auxiliary capacitance bus line 413 is formed so as to be in parallel with the gate bus line 412 in the center of each of the rectangular picture element regions defined by the gate bus lines 412 and the data bus lines 417.

In each of the picture element regions, a TFT 418, a control electrode 419a, an auxiliary capacitance electrode 419c and a picture element electrode 421 are formed.

With regard to the TFT 418, a part of the gate bus line 412 is used as the gate electrode. A drain electrode 418a and a source electrode 418b are arranged so as to be opposite to each other with the gate bus line 412 interposed therebetween. The control electrode 419a is electrically connected with the drain electrode 418a of the TFT 418. In addition, the auxiliary capacitance electrode 419c is formed in a position opposite to the auxiliary capacitance bus line 413 with a first insulating film interposed therebetween, and is electrically connected to the drain electrode 418a of the TFT 418 through the control electrode 419a.

The picture element electrode 421 is formed of a transparent conductive material such as ITO, and is divided into four fields (domain control fields) with a center line in parallel with the X axis and a center line in parallel with the Y axis defined as their boundaries. Alignment directions of liquid crystal molecules respectively of the four fields are different from one field to another. In a first field upper right, formed are slits 422a extending in a direction at an angle of 45 degrees to the X axis, slits 422b extending in a direction at an angle of 65 degrees to the X axis, as well as slits 422c made of a combination of slits extending in a direction at an angle of 45 degrees to the X axis and slits extending in a direction at an angle of 65 degrees to the X axis. In a second field upper left, formed are slits 422d extending in a direction at an angle of 135 degrees to the X axis, slits 422e extending in a direction at an angle of 115 degrees to the X axis, as well as slits 422f made of a combination of slits extending in a direction at an

angle of 135 degrees to the X axis and slits extending in a direction at an angle of 115 degrees to the X axis. Furthermore, in a third field lower left, formed are slits **422g** extending in a direction at an angle of 225 degrees to the X axis, slits **422h** extending in a direction at an angle of 245 degrees to the X axis, as well as slits **422i** made of a combination of slits extending in a direction at an angle of 225 degrees to the X axis and slits extending in a direction at an angle of 245 degrees to the X axis. Moreover, in a fourth field lower right, formed are slits **422j** extending in a direction at an angle of 315 degrees to the X axis, slits **422k** extending in a direction at an angle of 295 degrees to the X axis, as well as slits **422m** made of a combination of slits extending in a direction at an angle of 315 degrees to the X axis and slits extending in a direction at an angle of 295 degrees to the X axis.

The picture element electrode **421** is electrically connected to the auxiliary capacitance electrode **419c** through a contact hole **420a** formed in a second insulating film. The surface of the picture element electrode **421** is covered with a vertical alignment film made of polyimide or the like.

Incidentally, a dot-dashed line in FIG. 26 indicates a position of the edge of a black matrix to be formed in an opposing substrate. The opposing substrate of the liquid crystal display device according to the first example has the same structure as the opposing substrate of the liquid crystal display device according to the first embodiment. For this reason, descriptions will be omitted for the structure of the opposing substrate of the liquid crystal display device according to the first example. In addition, in the case of the liquid crystal display device according to the first example, a liquid crystal layer made of liquid crystal with negative dielectric anisotropy is arranged between the TFT substrate and the opposing substrate. The liquid crystal layer includes a polymer which has been made in the following process. A polymer component (a monomer or an oligomer) is added to the liquid crystal. Then, beams of ultraviolet light are irradiated to the polymer component while voltage is applied to the liquid crystal. Thereby, the polymer component is polymerized into the polymer. This polymer determines directions in which the liquid crystal molecules are aligned when voltage is applied.

In the case of the liquid crystal display device as shown in FIG. 1, for example in the first field, a force which causes the liquid crystal molecules in the vicinity of a connecting electrode part to tilt in a direction (a direction at an angle of 0 degrees) orthogonal to the connecting electrode part is added to the liquid crystal molecules due to a line of electric force generated by the connecting electrode part. The connecting electrode part is arranged along the center line of the picture element electrode, which center line is in parallel with the Y axis. In addition, a force which causes the liquid crystal molecules in the vicinity of the connecting electrode part to tilt in a direction at an angle of 45 degrees to the X axis is added to the liquid crystal molecules due to the slits. As a result, the liquid crystal molecules in the vicinity of the connecting electrode part actually tilt in a direction which makes the two forces balanced against each other. In other words, a direction in which the liquid crystal molecules in the vicinity of the connecting electrode part tilt is a direction at an angle of smaller than 45 degrees to the X axis.

On the other hand, in the case of the liquid crystal display device according to the present example as shown in FIG. 26, for example in the first field, a direction in which each of the slits in the vicinity of the connecting electrode part extends is a direction at an angle of larger than 45 degrees to the X axis. This enables the liquid crystal molecules in the vicinity of the connecting electrode part to tilt in a direction at an angle of approximately 45 degrees. Accordingly, a dark portion is

inhibited from occurring in the vicinity of the connecting electrode part, and the transmittance is improved. Furthermore, since the alignment stability of the liquid crystal molecules in the vicinity of the connecting electrode part is improved, the response characteristics are improved.

### Second Example

FIG. 27 is a plan view showing a picture element of a liquid crystal display device according to a second example of the tenth embodiment. The liquid crystal display device according to the second example is different from the liquid crystal display device according to the first example as shown in FIG. 26, in that the shape of each of the slits provided to the picture element electrode in the liquid crystal display device according to the second example is different from that in the liquid crystal display device according to the first example. Except for the shape of each of the slits, the liquid crystal display device according to the second example has basically the same constitution as the liquid crystal display device according to the first example. For this reason, if the components and equivalents in FIG. 27 were the same as, or similar to, those in FIG. 26, the components and equivalents in FIG. 27 are denoted by the same reference numerals and symbols as those in FIG. 26 are. Thus, detailed descriptions will be omitted for the same, or similar components and equivalents in FIG. 27.

In the case of the liquid crystal display device according to the second example, a picture element electrode **441** is divided into four fields (domain control fields) with a center line in parallel with the X axis and a center line in parallel with the Y axis defined as their boundaries, as shown in FIG. 27. Each of the fields is provided with slits **442** extending in a direction in parallel with the X axis. When voltage is applied, the liquid crystal molecules in each of the fields are aligned in a direction towards the center of the picture element electrode along the slits **442**. In other words, when voltage is applied, the liquid crystal molecules in the upper right and the lower right fields tilt in a direction at an angle of 180 degrees to the X axis, and the liquid crystal molecules in the upper left and the lower left fields tilt in a direction at an angle of 0 degrees to the X axis.

In the case of the liquid crystal display device according to the second example, the number of alignment divisions is two. For this reason, the liquid crystal display device according to the second example has worse viewing angle characteristics than the liquid crystal display device with the four alignment divisions according to the first example. However, a direction in which the liquid crystal molecules near each of the extremities respectively of the slits **442** (near the data bus line) tilt agrees with the direction in which each of the slits **442** extends. This brings about an advantage of avoiding a defect in alignment which would otherwise occur in each of the extremities respectively of the slits **442**. Moreover, alignment stability of the liquid crystal molecules in each of the extremities respectively of the slits **442** is improved.

### Third Example

FIG. 28 is a plan view showing a picture element of a liquid crystal display device according to a third example of the tenth embodiment. Incidentally, the liquid crystal display device according to the third example is different from the liquid crystal display device according to the first example as shown in FIG. 26, in that the shape of each of the slits provided to the picture element electrode in the liquid crystal display device according to the third example is different from that in the liquid crystal display device according to the

first example. Except for the shape of each of the slits, the liquid crystal display device according to the third example has basically the same constitution as the liquid crystal display device according to the first example. For this reason, if the components and equivalents in FIG. 28 were the same as, or similar to, those in FIG. 26, the components and equivalents in FIG. 28 are denoted by the same reference numerals and symbols as those in FIG. 26 are. Thus, detailed descriptions will be omitted for the same, or similar components and equivalents in FIG. 28.

In the case of the liquid crystal display device according to the third example, a picture element electrode 451 is divided into four fields (domain control fields) with a center line in parallel with the X axis and a center line in parallel with the Y axis defined as their boundaries, as shown in FIG. 28. A first field upper right is provided with slits 452a extending in a direction at an angle of 25 degrees to the X axis and slits 452b extending in a direction at an angle of 45 degrees to the X axis. Furthermore, a second field upper left is provided with slits 452c extending in a direction at an angle of 155 degrees to the X axis and slits 452d extending in a direction at an angle of 135 degrees to the X axis. In addition, a third field lower left is provided with slits 452e extending in a direction at an angle of 205 degrees to the X axis and slits 452f extending in a direction at an angle of 225 degrees to the X axis. Moreover, a fourth field lower right is provided with slits 452g extending in a direction at an angle of 335 degrees to the X axis and slits 452h extending in a direction at an angle of 315 degrees to the X axis.

In the case of the third example, too, one picture element region is divided into four fields (domain control fields) which are different from one another in alignment direction of liquid crystal molecules, by the slits provided to the picture element electrode 451. In addition, each of the fields is provided with slits extending in one of directions respectively at angles of 45 degrees, 135 degrees, 225 degrees and 315 degrees to the X axis, and with slits extending in one of directions respectively at angles of 25 degrees, 155 degrees, 205 degrees and 335 degrees to the X axis. Thereby, a dark portion can be inhibited from occurring in each of the extremities respectively of the slits (near the data bus line) in comparison with the liquid crystal display device shown in FIG. 1.

#### Fourth Example

FIG. 29 is a plan view showing a picture element of a liquid crystal display device according to a fourth example of the tenth embodiment. Incidentally, the liquid crystal display device according to the fourth example is different from the liquid crystal display device according to the first example as shown in FIG. 26, in that the shape of each of the slits provided to the picture element electrode in the liquid crystal display device according to the fourth example is different from that in the liquid crystal display device according to the first example. Except for the shape of each of the slits, the liquid crystal display device according to the fourth example has basically the same constitution as the liquid crystal display device according to the first example. For this reason, if the components and equivalents in FIG. 29 were the same as, or similar to, those in FIG. 26, the components and equivalents in FIG. 29 are denoted by the same reference numerals and symbols as those in FIG. 26 are. Thus, detailed descriptions will be omitted for the same, or similar components and equivalents in FIG. 29.

In the case of the liquid crystal display device according to the fourth example, too, a picture element electrode 461 is

divided into four fields (domain control fields) by a center line in parallel with the X axis and a center line in parallel with the Y axis defined as their boundaries, as shown in FIG. 29. A first field upper right is provided with slits 462a. With regard to each of the slits 462a, its portion near the base end (near the connecting electrode part) extends in a direction at an angle of 45 degrees to the X axis, and its portion near the extremity (near the data bus line) extends in a direction at an angle of 25 degrees to the X axis. In addition, a second field upper left is provided with slits 462b. With regard to each of the slits 462b, its portion near the base end extends in a direction at an angle of 135 degrees to the X axis, and its portion near the extremity extends in a direction at an angle of 155 degrees to the X axis. Furthermore, a third field lower left is provided with slits 462c. With regard to each of the slits 462c, its portion near the base end extends in a direction at an angle of 225 degrees to the X axis, and its portion near the extremity extends in a direction at an angle of 205 degrees to the X axis. Moreover, a fourth field lower right is provided with slits 462d. With regard to each of the slits 462d, its portion near the base end extends in a direction at an angle of 315 degrees to the X axis, and its portion near the extremity extends in a direction at an angle of 335 degrees to the X axis.

In the case of the fourth example, too, one picture element region is divided into four fields which are different from one another in alignment direction of liquid crystal molecules, by the slits provided to the picture element electrode 461. In addition, the extremity of each of the slits is provided at an angle of approximately 90 degrees to the data bus line 417.

Accordingly, a dark portion can be inhibited from occurring in the extremity of each of the slits. Furthermore, the alignment stability of the liquid crystal molecules in the extremity of each of the slits is improved. Moreover, it was proved that, if the width of each of the microelectrode parts near the data bus line were made larger as in the case of the fourth example, this inhibits display unevenness from occurring due to a stepper exposure process to be performed while an ITO film is being patterned.

#### Eleventh Example

As described above, if a sub picture element electrode (directly-connected picture element electrode) directly connected to a TFT and a sub picture element electrode (capacitively-coupled picture element electrode) connected to the TFT through capacitive coupling were formed in a single picture element, this can inhibit the display quality from being deteriorated when the screen is viewed in an oblique direction.

FIG. 30 is a diagram showing relationship among white display voltage, a directly-connected picture element electrode ratio and an amount of difference in gamma values, which relationship is observed while the horizontal axis represents the white display voltage, and while the vertical axis represents a ratio of an area of the directly-connected picture element electrode to an area of the entire picture element electrode (the directly-connected picture element electrode ratio). In FIG. 30, if the directly-connected picture element electrode ratio were 0%, this means that the entire picture element electrode is constituted only of the capacitively-coupled picture element electrode. If the directly-connected picture element electrode ratio were 100%, this means that the entire picture element electrode is constituted only of the directly-connected picture element electrode. The amount of difference in gamma values represents an average of differences between the respective gamma values to be observed when the liquid crystal panel is viewed from the front and the

respective gamma values to be observed when the liquid crystal panel is viewed in a direction at a polar angle of 60 degrees (in a direction at an angle of 60 degrees to the normal line of the panel). This diagram shows that, the smaller the amount of difference in gamma values is, the better the display quality to be observed when the panel is viewed in an oblique direction is.

In the case of the liquid crystal display device (a conventional example) as shown in FIG. 1, the directly-connected picture element electrode ratio is 100%. For this reason, according to FIG. 30, if the white display voltage were 6V, the amount of difference in gamma values is 2. In addition, according to FIG. 30, if the directly-connected picture element electrode ratio were in a range of 10% to 40% and the white display voltage were 4V, the amount of difference in gamma values is less than or equal to 1. It is learned through this that the display quality to be observed when the liquid crystal panel is viewed in an oblique direction is preferable. In this case, however, the white display voltage is lower, accordingly darkening the screen. In a case where the white display voltage is 6V, if the area ratio of the directly-connected picture element electrode were in a range of 10% to 70%, this enables the display to be brighter. Concurrently, this causes the amount of difference in gamma values to be less than 1.4. Accordingly, a relatively preferable display quality can be maintained even when the panel is viewed in an oblique direction. As a consequence, it is preferable that the area ratio of the directly-connected picture element electrode be in a range of 10% to 70%.

FIG. 31 is a plan view showing a liquid crystal display device (Part 1) according to an eleventh embodiment of the present invention. In the case of this liquid crystal display device, the width L1 of each of the microelectrode parts of a directly-connected picture element electrode 511b is 5  $\mu\text{m}$ ; the width S1 of each of the slits of the directly-connected picture element electrode 511b is 3.5  $\mu\text{m}$ ; the width L2 of each of the microelectrode parts of capacitively-coupled picture element electrodes 511a and 511c is 4  $\mu\text{m}$ ; the width S2 of each of the slits of the capacitively-coupled picture element electrodes 511a and 511c is 3.5  $\mu\text{m}$ ; and a ratio of an area M of the directly-connected picture element electrode 511b to an area S aggregating areas respectively of the capacitively-coupled picture element electrodes 511a and 511c is 5:5 (i.e. M:S=5:5).

FIG. 32 is a plan view showing a liquid crystal display device (Part 2) according to the eleventh embodiment of the present invention. In the case of this liquid crystal display device, the width L1 of each of the microelectrode parts of a directly-connected picture element electrode 511b is 6  $\mu\text{m}$ ; the width S1 of each of the slits of the directly-connected picture element electrode 511b is 3.5  $\mu\text{m}$ ; the width L2 of each of the microelectrode parts of capacitively-coupled picture element electrodes 511a and 511c is 4  $\mu\text{m}$ ; the width S2 of each of the slits of the capacitively-coupled picture element electrodes 511a and 511c is 3.5  $\mu\text{m}$ ; and a ratio of an area M of the directly-connected picture element electrode 511b to an area S aggregating areas respectively of the capacitively-coupled picture element electrodes 511a and 511c is 5:5 (i.e. M:S=5:5).

FIG. 33 is a plan view showing a liquid crystal display device (Part 3) according to the eleventh embodiment of the present invention. In the case of this liquid crystal display device, the width L1 of each of the microelectrode parts of a directly-connected picture element electrode 511b is 6  $\mu\text{m}$ ; the width S1 of each of the slits of the directly-connected picture element electrode 511b is 3.5  $\mu\text{m}$ ; the width L2 of each of the microelectrode parts of capacitively-coupled picture

element electrodes 511a and 511c is 4  $\mu\text{m}$ ; the width S2 of each of the slits of the capacitively-coupled picture element electrodes 511a and 511c is 3.5  $\mu\text{m}$ ; and a ratio of an area M of the directly-connected picture element electrode 511b to an area S aggregating areas respectively of the capacitively-coupled picture element electrodes 511a and 511c is 4:6 (i.e. M:S=4:6).

FIG. 34 is a plan view showing a liquid crystal display device (Part 4) according to the eleventh embodiment of the present invention. In the case of this liquid crystal display device, the width L1 of each of the microelectrode parts of a directly-connected picture element electrode 511b is 6  $\mu\text{m}$ ; the width S1 of each of the slits of the directly-connected picture element electrode 511b is 3.5  $\mu\text{m}$ ; the width L2 of each of the microelectrode parts of capacitively-coupled picture element electrodes 511a and 511c is 4  $\mu\text{m}$ ; the width S2 of each of the slits of the capacitively-coupled picture element electrodes 511a and 511c is 3.5  $\mu\text{m}$ ; and a ratio of an area M of the directly-connected picture element electrode 511b to an area S aggregating areas respectively of the capacitively-coupled picture element electrodes 511a and 511c is 3:7 (i.e. M:S=3:7).

If the width of each of the microelectrode parts were made larger, this can inhibit display unevenness from occurring due to a stepper exposure process to be performed while the ITO film is being patterned. However, this makes weaker a force to control alignment of the liquid crystal molecules. As shown in FIGS. 31 to 34, if the width of each of the microelectrode parts of the directly-connected picture element electrode 511b were made larger, and concurrently if the width of each of the microelectrode parts of the capacitively-coupled picture element electrodes 511a and 511c were made smaller, this can inhibit display unevenness from occurring due to the stepper exposure process while the force to control the alignment of the liquid crystal molecules is being maintained. In addition, if the directly-connected picture element electrode ratio were in a range of 10% to 70%, this makes the amount of difference in gamma values smaller. Accordingly, this improves the display quality to be observed when the screen is viewed in an oblique direction.

With regard to the aforementioned first embodiment (see FIG. 3), descriptions have been provided of the case where the single picture element is provided with the directly-connected picture element electrode and the capacitively-coupled picture element electrodes and accordingly a plurality of fields whose transmittance-applied voltage characteristics (T-V characteristics) are different from each other are formed in the single picture element. If, however, conditions (an intensity and a wavelength of a beam of ultraviolet light, and the like) where the polymer component added to the liquid crystal is polymerized were changed, this also can form, in the single picture element, a plurality of fields whose transmittance-applied voltage characteristics are different from each other.

When the polymer component added to the liquid crystal is intended to be polymerized, conditions under which voltage is applied may be changed for each of a red (R) picture element, a green (G) picture element and a blue (B) picture element, thereby irradiating beams of ultraviolet light. This can uniform the gamma characteristics respectively of the red (R) picture element, the green (G) picture element and the blue (B) picture element. Accordingly, this can realize a liquid crystal display device whose color deviation is extremely little.

In addition, if a single picture element were provided with fields whose monomers are polymerized under conditions different from one field to another, a plurality of fields whose

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transmittance-applied voltage characteristics are different from one field to another can be formed in the single picture element. Otherwise, if a single picture element were provided with fields which are different from one field to another in surface energy of the substrate surface and thereafter the polymer component added to the liquid crystal is polymerized, a plurality of fields whose transmittance-applied voltage characteristics are different from one field to another can be formed in the single picture element. For example, if a resin film were formed on parts of the substrate, conditions under which the monomer added to the liquid crystal is polymerized can be changed, and the surface energy of the substrate surface can be changed.

Furthermore, if the single picture element were provided with a plurality of types of fields which are different from one another in width of their microelectrode parts and in the width of their slits (a line and a space), the plurality of types of fields whose transmittance-applied voltage characteristics are different from one field to another can be formed in the single picture element.

Furthermore, the polymer component added to the liquid crystal may be polymerized by use of a heating process, although the polymer component added to the liquid crystal according to each of the aforementioned embodiments is polymerized by irradiating beams of ultraviolet light to the polymer component. Otherwise, the polymer component may be polymerized by use of both a process of irradiating beams of ultraviolet light to the polymer component and a process of heating the polymer component.

Moreover, in order to compensate an optical anisotropy of the liquid crystal layer, an optical phase-difference film which has a slow axis in a direction in parallel with the substrate surface (the surface of the liquid crystal panel) may be arranged in the case of each of the aforementioned embodiments.

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What is claimed is:

1. A liquid crystal display device comprising:

a first substrate and a second substrate which are arranged to be opposite to each other;

liquid crystal contained between said first and said second substrates;

a plurality of gate bus lines extending in a first direction;

a plurality of drain bus lines extending in a second direction, wherein said second direction is different from said first direction; and

a picture element electrode,

wherein said picture element electrode includes a body portion and a plurality of branches extending from said body portion, with said branches being separated from each other by a plurality of slits,

wherein said body portion includes a first body portion extending generally in said first direction and a second body portion extending generally in said second direction,

wherein said first body portion includes at least one wide portion and at least one narrow portion, and

wherein said liquid crystal display device further comprises:

a capacitor electrode overlapping said wide portion,

a capacitor upper electrode overlapping said wide portion, and

wherein said capacitor upper electrode connects to said picture element electrode through a contact hole formed at said wide portion.

2. The liquid crystal display device according to claim 1, wherein said contact hole is formed at a location where said first body portion crosses said second body portion.

\* \* \* \* \*

|                |                                                                                                                                                                                                                                                     |         |            |
|----------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------|------------|
| 专利名称(译)        | 液晶显示装置                                                                                                                                                                                                                                              |         |            |
| 公开(公告)号        | <a href="#">US7920239</a>                                                                                                                                                                                                                           | 公开(公告)日 | 2011-04-05 |
| 申请号            | US12/785215                                                                                                                                                                                                                                         | 申请日     | 2010-05-21 |
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| IPC分类号         | G02F1/1337 G02F1/1343                                                                                                                                                                                                                               |         |            |
| CPC分类号         | G02F1/133707 G02F1/136286 G02F1/1334 G02F1/133512 G02F1/133514 G02F1/134309 G02F1/134336 G02F1/1393 G02F2001/133757 G02F2001/134345 G02F1/133711 G02F2001/133761                                                                                    |         |            |
| 优先权            | 2005001356 2005-01-06 JP<br>11/104309 2010-05-04 US                                                                                                                                                                                                 |         |            |
| 其他公开文献         | US20110001913A1                                                                                                                                                                                                                                     |         |            |
| 外部链接           | <a href="#">Espacenet</a> <a href="#">USPTO</a>                                                                                                                                                                                                     |         |            |

#### 摘要(译)

一种液晶显示装置，包括第一和第二基板，基板之间的液晶，沿第一方向延伸的多条栅极总线，沿第二方向延伸的多条漏极总线，以及像素电极。像素电极包括主体部分和由狭缝分开的多个分支，所述分支从其延伸。主体部分包括大致沿第一方向延伸的第一主体部分和大致沿第二方向延伸的第二主体部分，并且其中第一主体部分包括至少一个宽部分和至少一个窄部分。液晶显示装置还包

括电容器电极和与宽部分重叠的电容器上电极。电容器上电极通过形成在宽部分处的接触孔连接到像素电极。

