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Display Device

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(54) **DISPLAY DEVICE**

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G02F 1/1333 (2006.01)
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CPC ***G02F 1/134363*** (2013.01); ***G02F 1/133371*** (2013.01); ***G02F 1/133707*** (2013.01)
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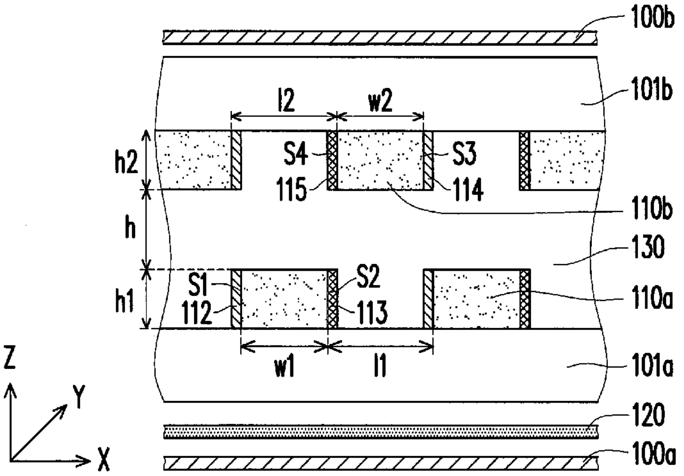
(57) **ABSTRACT**

A display device includes a first substrate, at least a first protrusion, a first electrode, a second substrate, at least a second protrusion, a second electrode and a display medium. The first protrusion is disposed on the first substrate. The first electrode is disposed on the first protrusion. The second substrate is disposed opposite to the first substrate. The second protrusion is disposed on the second substrate. The second electrode is disposed on the second protrusion, wherein the first electrode and the second electrode are displaced in a horizontal direction so as to form a lateral electric field therebetween. The display medium is sandwiched between the first and the second substrates.

9 Claims, 12 Drawing Sheets



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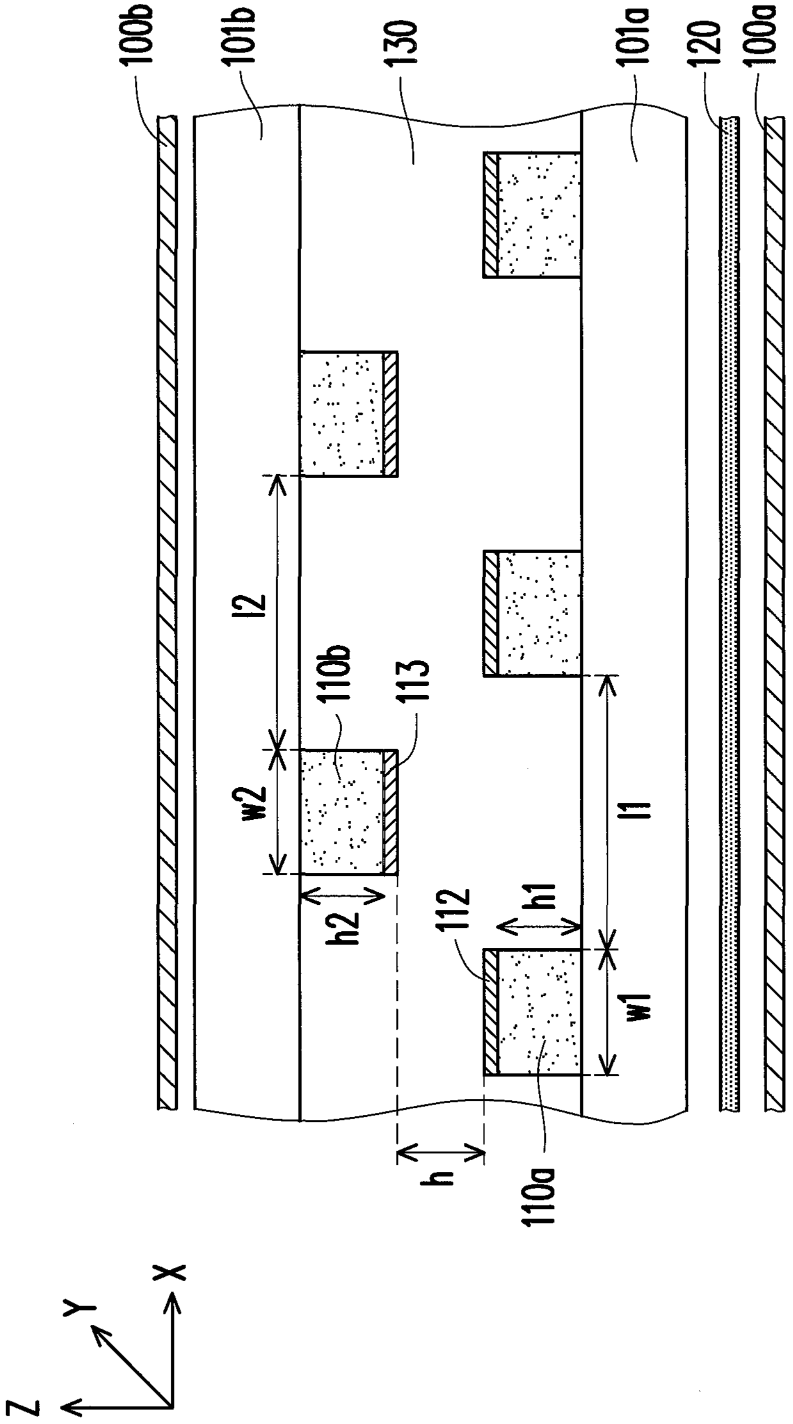
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101b
130
101a
120
100a
l2
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113
w2
h2
112
h1
l1
w1
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X
Y
Z

FIG. 1A

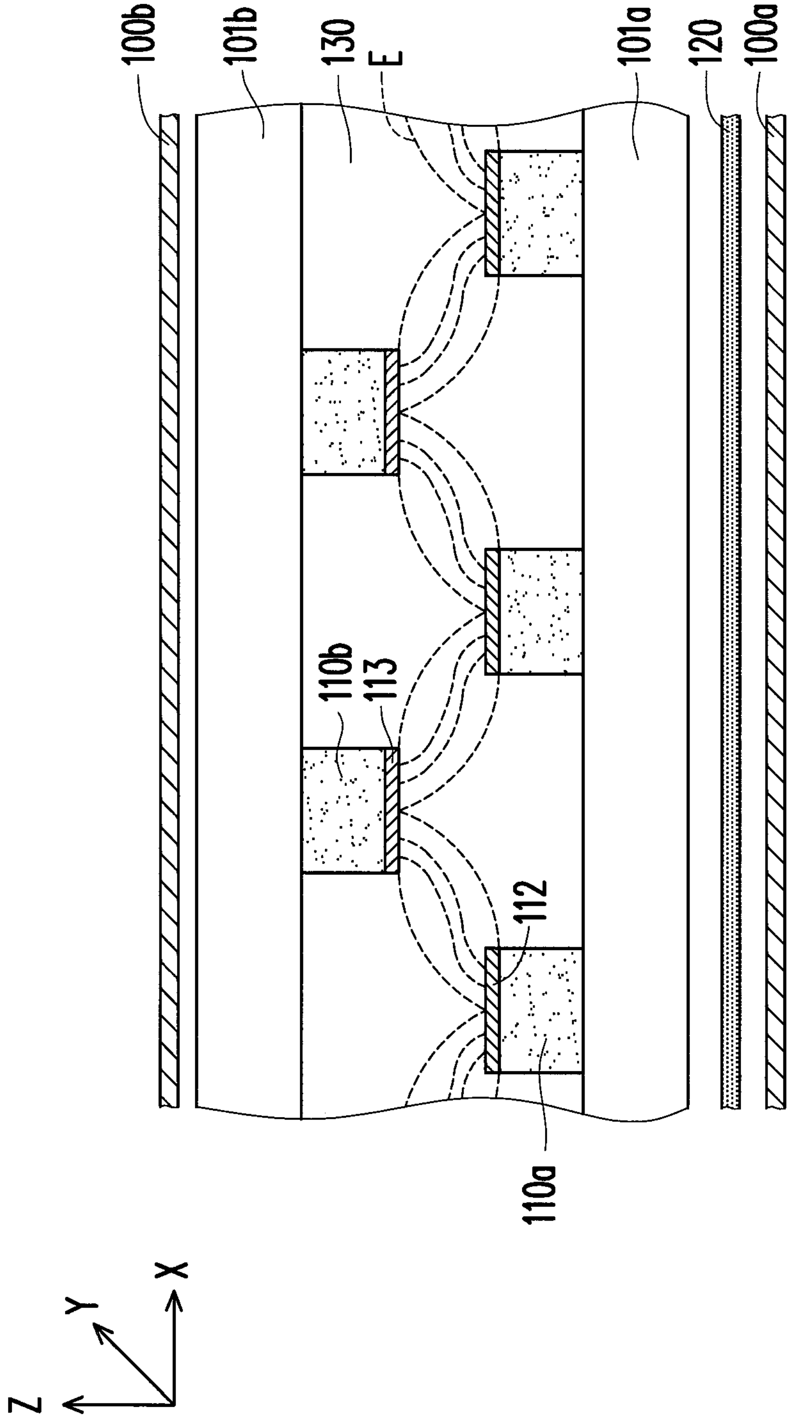


FIG. 1B

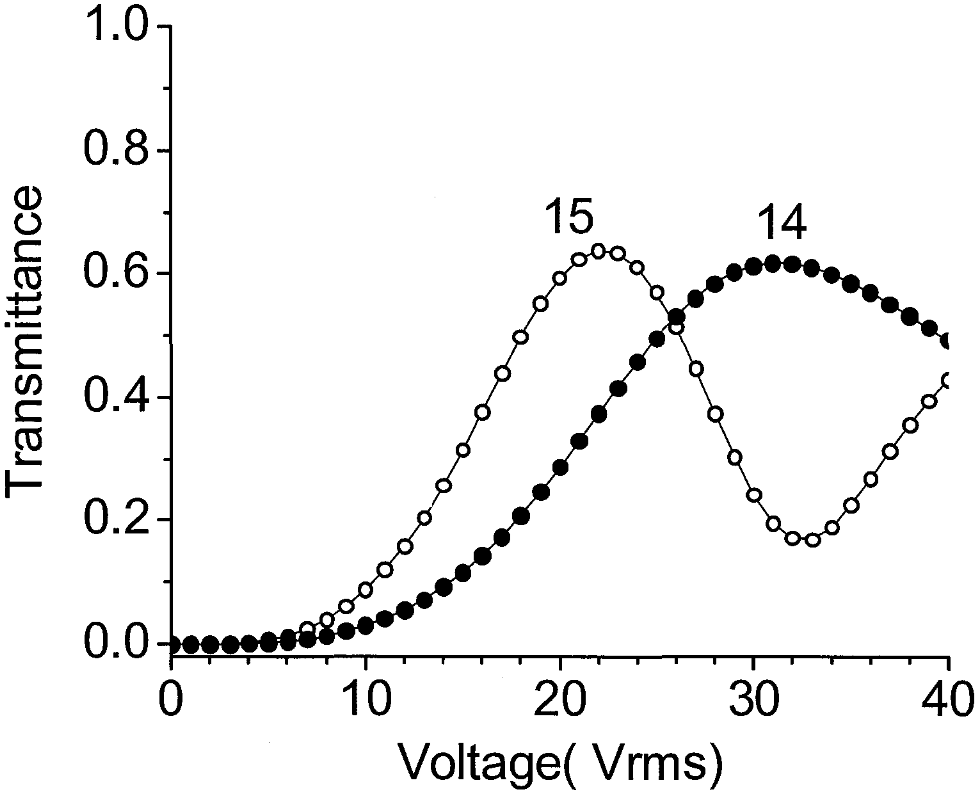


FIG.2

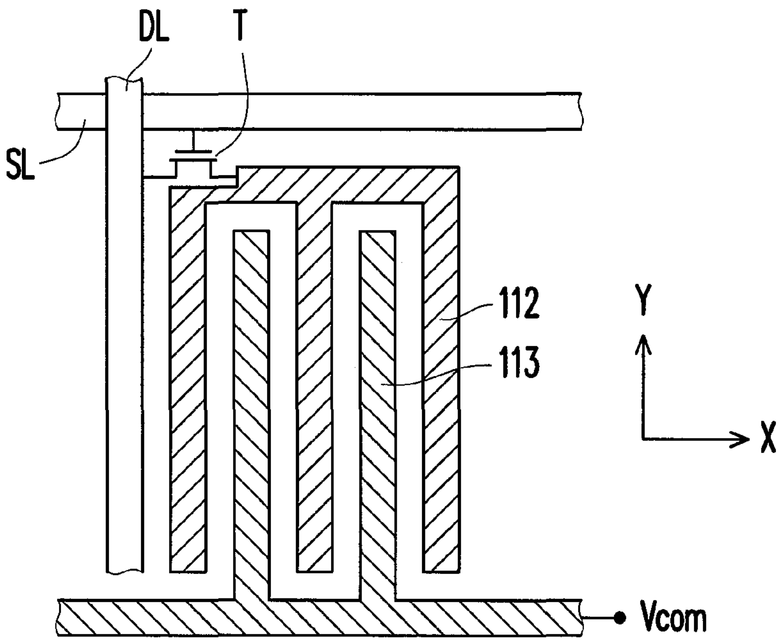


FIG. 3A

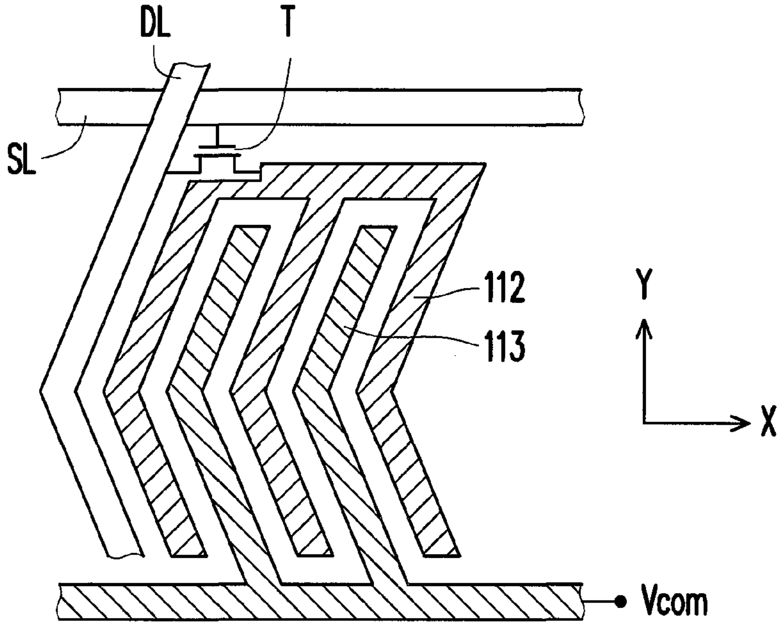
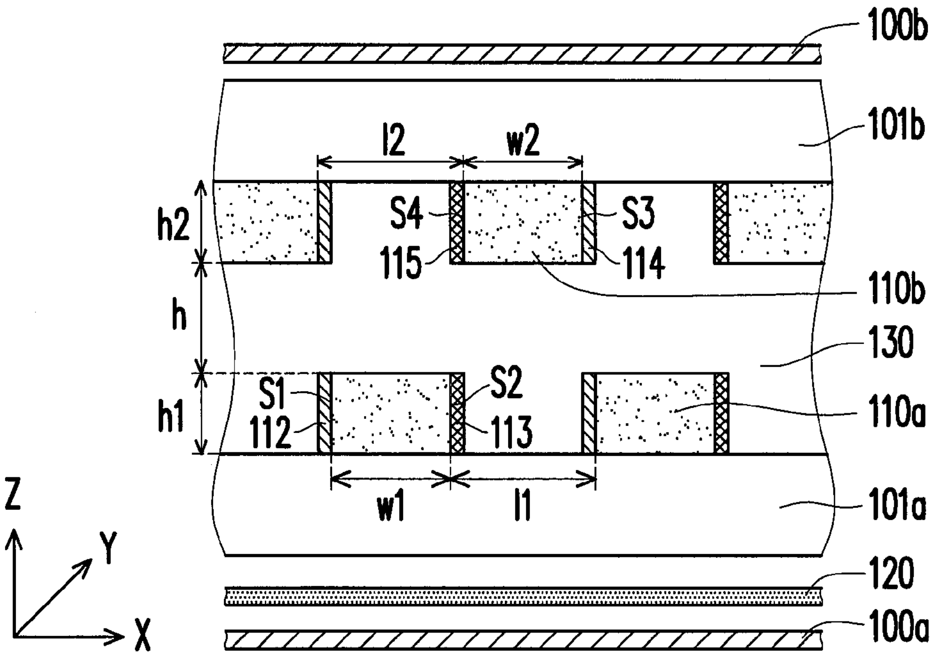


FIG. 3B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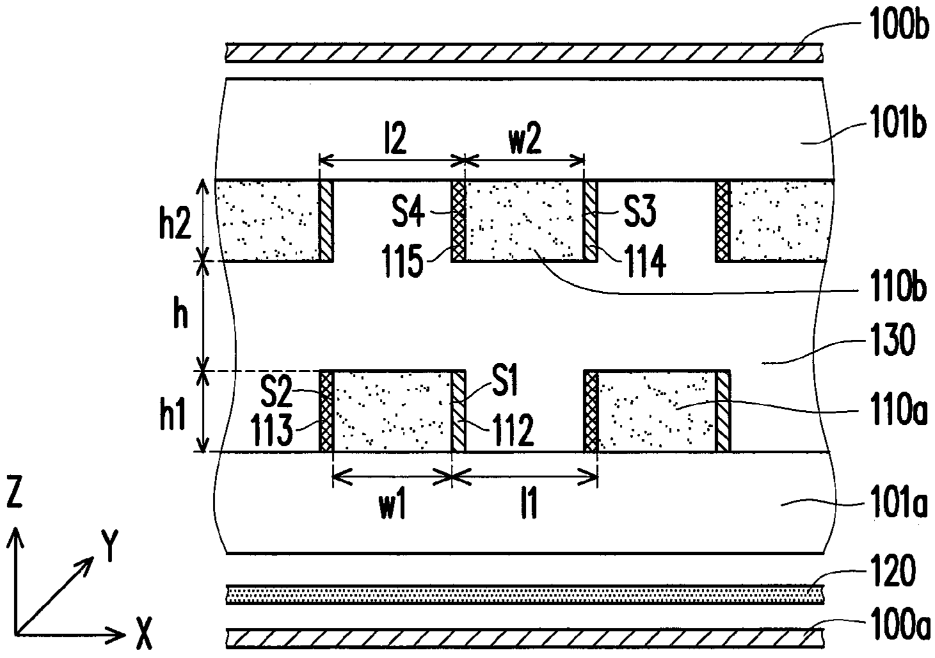
101b
l2
w2
h2
S4
S3
115
114
110b
h
130
h1
S1
S2
112
113
110a
w1
l1
101a
Z
Y
X
120
100a

FIG. 4A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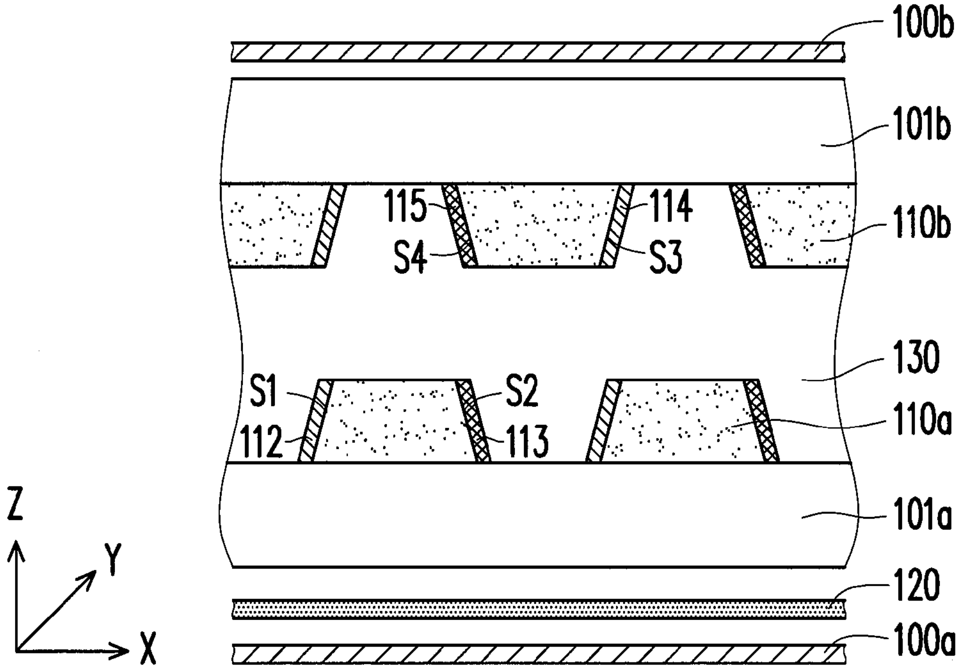
101b
l2
w2
h2
S4
S3
115
114
110b
h
130
h1
S2
S1
113
112
110a
w1
l1
101a
Z
Y
X
120
100a

FIG. 4B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114
110b
S4
S3
130
S1
S2
110a
112
113
101a
Z
Y
X
120
100a

FIG. 4C

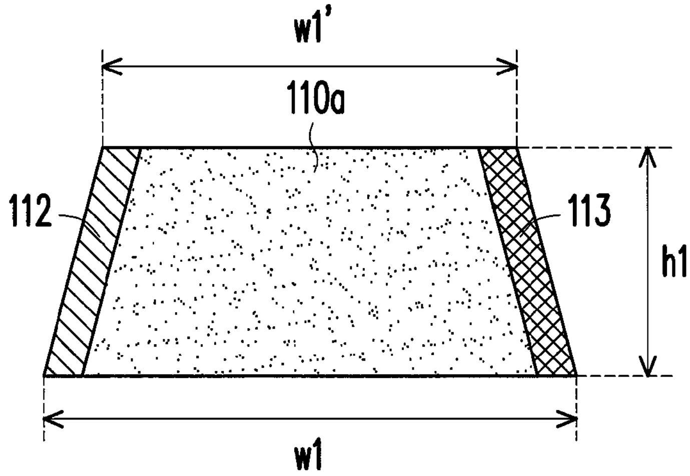

w1'
110a
112
113
h1
w1

FIG. 4D

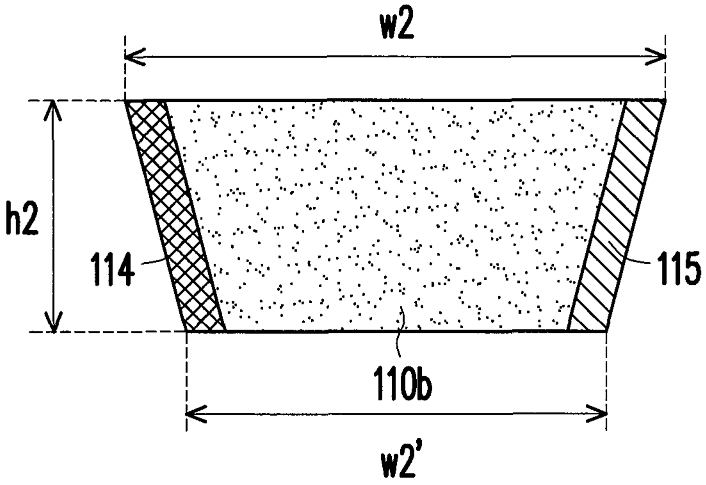
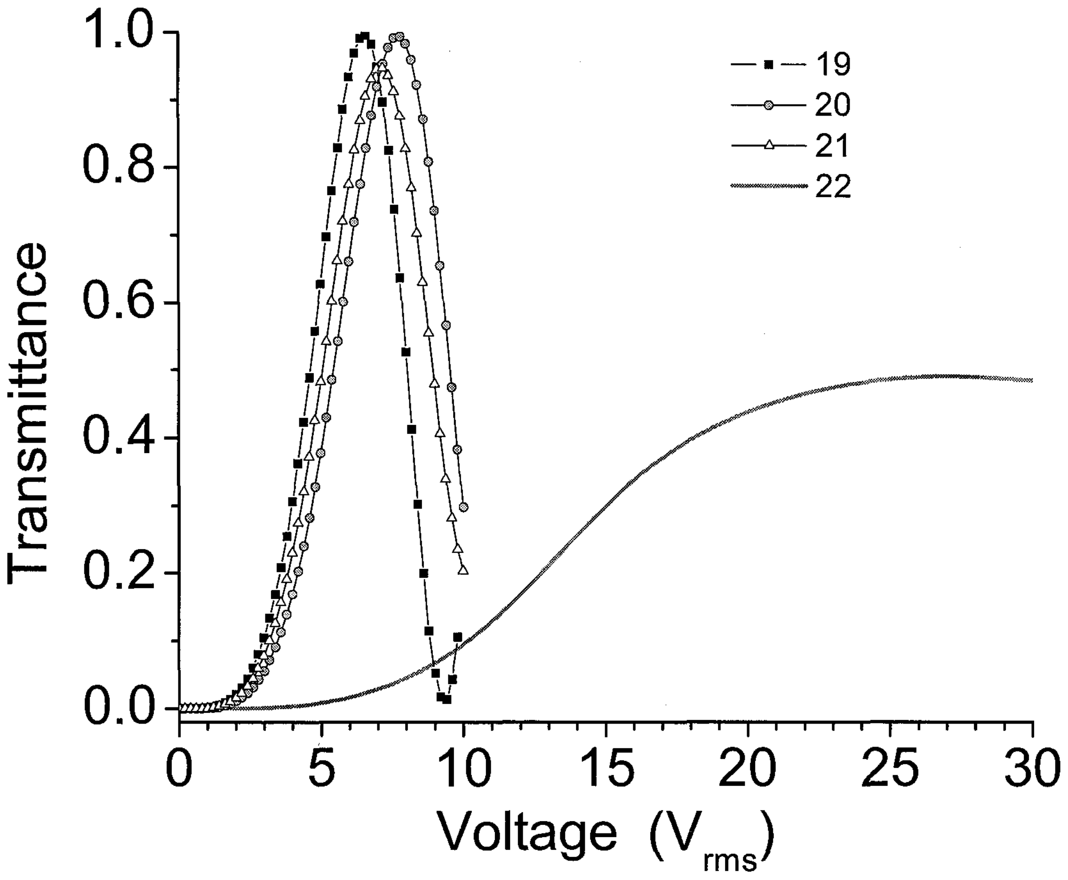
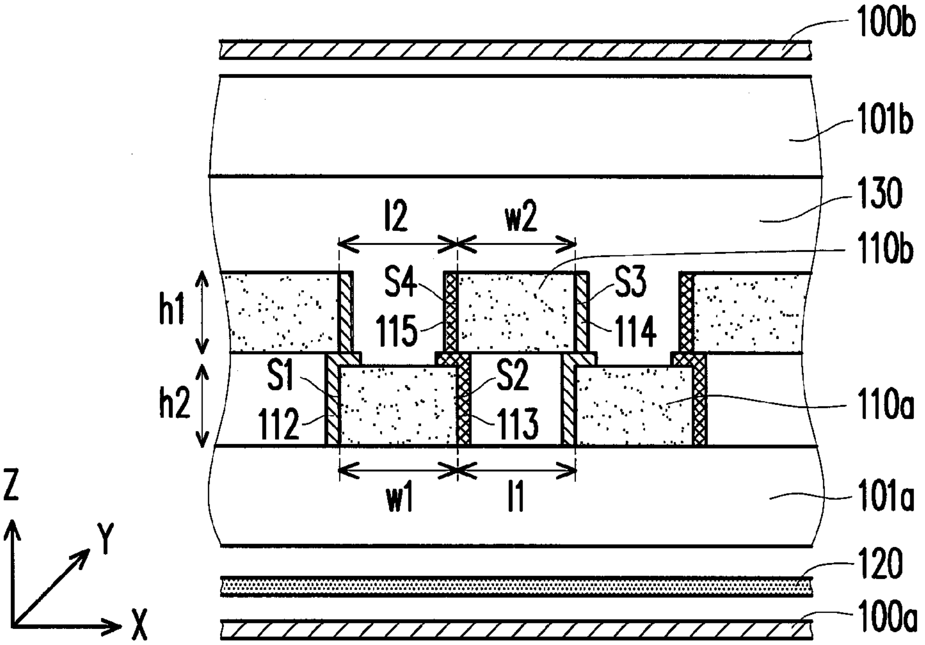


FIG. 4E



1.0
0.8
0.6
0.4
0.2
0.0
Transmittance
0
5
10
15
20
25
30
Voltage (V_rms)
19
20
21
22

FIG.5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w2
110b
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S3
h1
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114
S1
S2
h2
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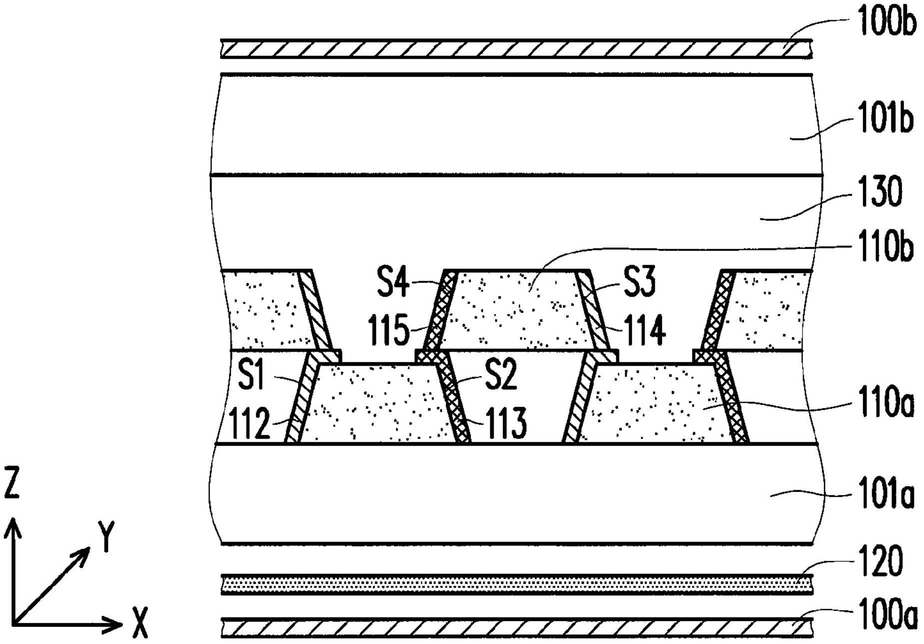
l1
101a
Z
Y
X
120
100a

FIG. 6A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S4
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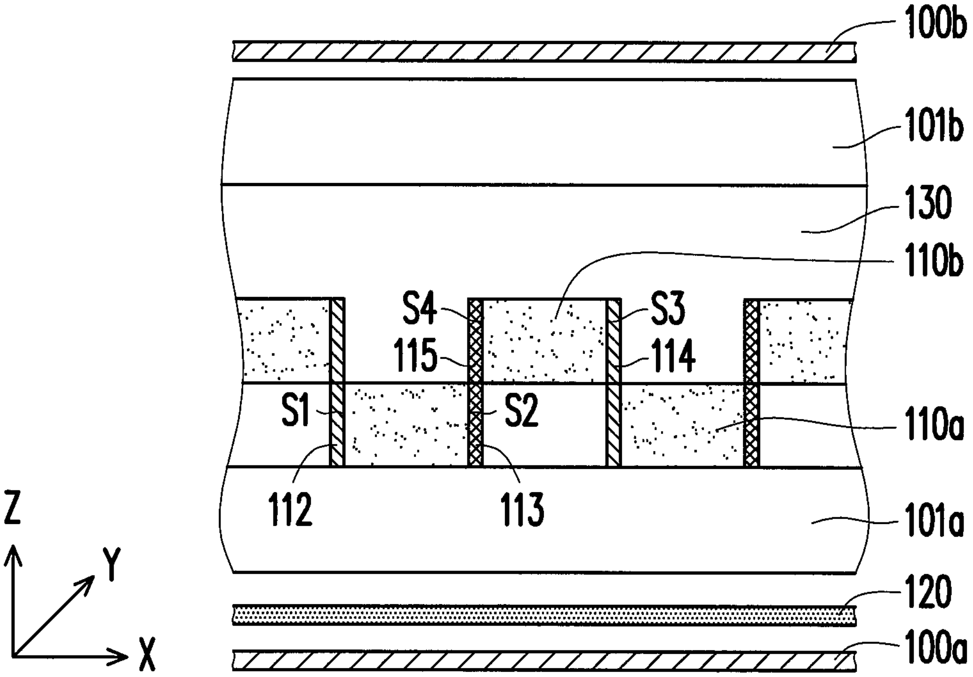
101a
Z
Y
X
120
100a

FIG. 6B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101b
130
110b
S4
S3
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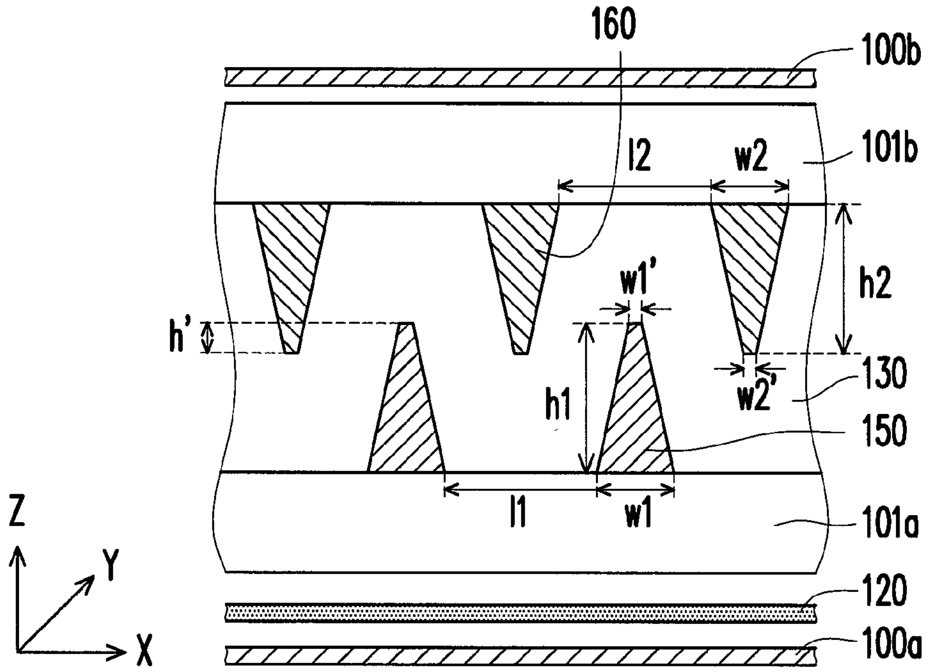
S1
S2
110a
112
113
101a
120
100a
Z
Y
X

FIG. 6C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100b
l2
w2
101b
w1'
h2
h'
130
w2'
h1
150
l1
w1
101a
Z
Y
X
120
100a

FIG. 7A

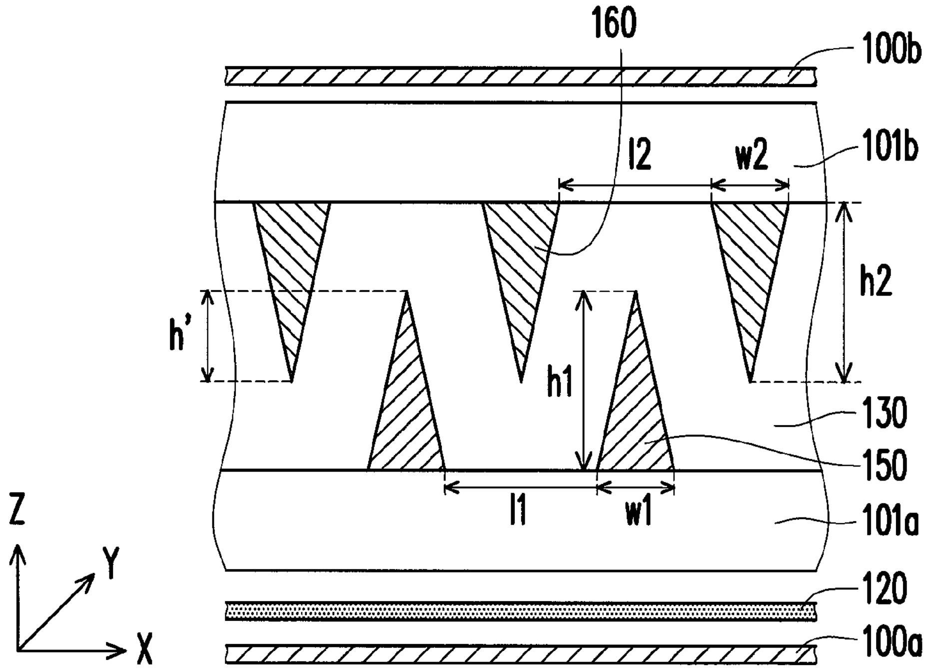
160
100b
l2
w2
101b
h2
h'
h1
130
150
l1
w1
101a
Z
Y
X
120
100a

FIG. 7B

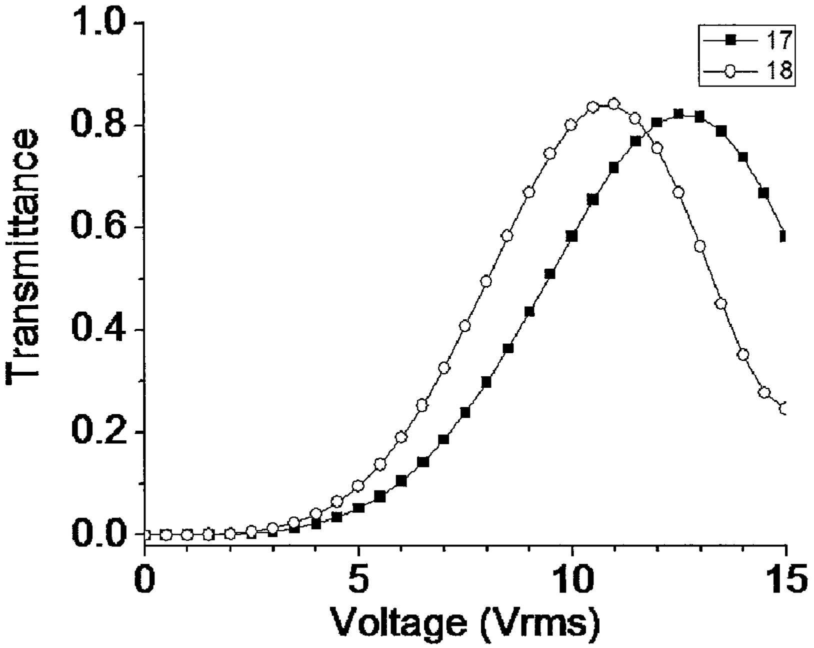

FIG.8

DISPLAY DEVICE

CROSS-REFERENCE TO RELATED APPLICATION

This application claims the priority benefit of U.S.A. provisional application Ser. No. 61/500,631, filed on Jun. 24, 2011. The entirety of the above-mentioned patent application is hereby incorporated by reference herein and made a part of specification.

BACKGROUND OF THE DISCLOSURE

1. Technical Field

The disclosure is related to a display device for a low driving voltage display using optically isotropic liquid crystals that is useful for displays with high light efficiency and fast response time.

2. Background

With booming development of technology, consumers have higher demands on display quality of displays. Besides demands for specifications of resolution, contrast ratio, viewing angle, grey level inversion and color saturation of the display, the consumers have higher demands for the response time of the display.

To meet the needs of the consumers, display practitioners devote to developing blue phase liquid crystal displays (LCDs) having a quick response characteristic. Taking a blue phase liquid crystal material as an example, a horizontal electric field is generally required to achieve a light valve function thereof. Currently, an electrode design of an in-plane switching (IPS) display module is used to drive the blue phase liquid crystal molecules in the blue phase LCD.

However, in the electrode design of a typical IPS display module, many regions above the electrodes do not have the horizontal electric field, and many liquid crystal molecules in the blue phase LCD cannot be fluently driven, which may lead to low transmittance of the display module. If a high driving voltage is needed in the IPS display module, power consumption is also high. Therefore, how to resolve the problems of low transmittance and high driving voltage of the blue phase LCD is an important issue to be developed.

SUMMARY

A display device includes a first substrate, at least one first protrusion, a first electrode, a second substrate, at least one second protrusion, a second electrode and a display medium. The first protrusion is disposed on the first substrate. The first electrode is disposed on the first protrusion. The second substrate is disposed opposite to the first substrate. The second protrusion is disposed on the second substrate. The second electrode is disposed on the second protrusion, wherein the first electrode and the second electrode are displaced in a horizontal direction so as to form a lateral electric field therebetween, and the smallest gap between the first electrode and the second electrode in a vertical direction ranges from −100 μm to 100 μm. The display medium is sandwiched between the first and the second substrates.

A display device includes a first substrate, a plurality of first protrusions, a first electrode, a second electrode, a plurality of second protrusions, a third electrode, a fourth electrode and a display medium. The first protrusions are disposed on the first substrate, and each first protrusion has a first side wall and a second side wall. The first electrode is disposed on the first side wall of each first protrusion. The second electrode is disposed on the second side wall of each first protrusion, wherein a lateral electric field is formed between the first electrode on each first protrusion and the second electrode on the adjacent first protrusion. The second substrate is disposed opposite to the first substrate. The second protrusions are disposed on the second substrate, and each second protrusion has a third side wall and a fourth side wall. The third electrode is disposed on the third side wall of each second protrusion. The fourth electrode is on the fourth side wall of each second protrusion, wherein a lateral electric field is formed between the third electrode on each second protrusion and the fourth electrode on the adjacent second protrusion. The display medium is sandwiched between the first and the second substrates.

A display device includes a first substrate, a plurality of first protrusions, a first electrode, a second electrode, a plurality of second protrusions, a third electrode, a fourth electrode, a second substrate and a display medium. The first protrusions are disposed on the first substrate, and each first protrusion has a first side wall and a second side wall. The first electrode is disposed on the first side wall of each first protrusion. The second electrode is disposed on the second side wall of each first protrusion, wherein a lateral electric field is formed between the first electrode on each first protrusion and the second electrode on the adjacent first protrusion. The second protrusions are stacked on the first protrusions, and each second protrusion has a third side wall and a fourth side wall. The third electrode is disposed on the third side wall of each second protrusion and contacts with the first electrode on the first protrusions. The fourth electrode is disposed on the fourth side wall of each second protrusion and contacts with the second electrode on the first protrusions, wherein a lateral electric field is formed between the third electrode on each second protrusion and the fourth electrode on the adjacent second protrusion. The second substrate is opposite to the first substrate. The display medium is sandwiched between the first and the second substrates.

A display device comprises a first substrate, at least one first bump electrode, a second substrate, at least one second bump electrode, and a display medium. The first bump electrode is disposed on the first substrate. The second substrate is opposite to the first substrate. The second bump electrode is disposed on the second substrate, wherein the first bump electrode and the second bump electrode are displaced in a horizontal direction so as to form a lateral electric field therebetween, and a overlapping height between the first bump electrode and the second bump electrode in the vertical direction is larger than 0 and smaller than a cell gap between the first substrate and the second substrate. The display medium is sandwiched between the first and the second substrates.

Several exemplary embodiments accompanied with figures are described in detail below to further describe the disclosure in details.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings are included to provide further understanding, and are incorporated in and constitute a part of this specification. The drawings illustrate exemplary embodiments and, together with the description, serve to explain the principles of the disclosure.

FIG. **1**A and FIG. **1**B show a schematic diagram of a pixel structure of a LCD according to a first exemplary embodiment.

FIG. **2** shows the VT curves of the pixel structure of the LCD in the first exemplary embodiment.

FIG. **3**A is a schematic diagram showing a top view of the pixel structure in the first exemplary embodiment.

FIG. **3**B is another schematic diagram showing a top view of the pixel structure in the first exemplary embodiment.

FIG. **4**A, FIG. **4**B and FIG. **4**C show the schematic diagrams of a pixel structure of a LCD according to a second exemplary embodiment, and FIG. **4**D and FIG. **4**E show the schematic diagrams of the first and second protrusions of FIG. **4**C.

FIG. **5** shows the VT curves of the pixel structure of the LCD in the second exemplary embodiment.

FIG. **6**A, FIG. **6**B and FIG. **6**C show the schematic diagrams of a pixel structure of a LCD according to a third exemplary embodiment.

FIG. **7**A and FIG. **7**B show the schematic diagrams of a pixel structure of a LCD according to a fourth exemplary embodiment.

FIG. **8** shows the VT curves of the pixel structure of the LCD in the fourth exemplary embodiment.

DETAILED DESCRIPTION OF DISCLOSED EMBODIMENTS

The exemplary embodiments will be explained in more details with reference to the accompanying drawings. However, this invention may be embodied in more different forms, and should not be limited in its application to the details of the particular arrangements shown. Also, the terminology used herein is for the purpose of description and not of limitation. The method, system and device of the present invention disclose a design for producing a high aperture ratio, high transmittance, and wide viewing angle LCD device.

First Exemplary Embodiment

FIG. **1**A and FIG. **1**B show a schematic diagram of a pixel structure of a LCD according to a first exemplary embodiment. As shown in FIG. **1**A, the display device includes a first substrate **101***a*, at least one first protrusion **110***a*, a first electrode **112**, a second substrate **101***b*, at least one second protrusion **110***b*, a second electrode **113** and a display medium **130**.

The first substrate **101***a* and the second substrate **101***b* are disposed opposite to each other and can be made of glass, quartz, an organic polymer, an opaque/reflective material (such as a conductive material, metal, wafer, ceramics, or any other appropriate material), or any other appropriate material.

The first protrusion **110***a* is disposed on the first substrate **101***a*. The second protrusion **110***b* is disposed on the second substrate **101***b*. The first protrusion **110***a* and the second protrusion **110***b* are made of a polymer, an inorganic material or any other suitable material. The first protrusion **110***a* and the second protrusion **110***b* are displaced in a horizontal direction. According to the embodiment, the first protrusion **110***a* and the second protrusion **110***b* are misaligned to each other in XY plane, and thus the first protrusion **110***a* and the second protrusion **110***b* are not overlapped to each other in XY plane. In addition, the first protrusion **110***a* and the second protrusion **110***b* have the same or different shapes from the cross-sectional view, and can take any shape that fabrication allows rather than rectangular as shown in FIG. **1**. The thickness h**1** of the first protrusion **110***a* and the thickness h**2** of the second protrusion **110***b* could be from 0.2 μm to 100 μm. In addition, the width w**1** of the first protrusion **110***a* and the width w**2** of the second protrusion **110***b* may be the same or different, which respectively range from 0.2 μm to 100 μm. The gap l1 between two adjacent first protrusions **110***a* on the first substrate **101***a* and the gap l2 between two adjacent second protrusions **110***b* on the second substrate **101***b* may respectively range from 0.2 μm to 100 μm.

The first electrode **112** is disposed on the first protrusion **110***a*. The second electrode **113** is disposed on the second protrusion **110***b*. The first electrode **112** and the second electrode **113** respectively have a thickness ranged from 0.001 μm to 10 μm. The first electrode **112** and the second electrode **113** are displaced in the horizontal direction so as to form a lateral electric field E therebetween, as shown in FIG. **1**B. The first electrode **112** and the second electrode **113** can be made of a metal, a transparent conductive material or any other suitable electrode material. In particular, the smallest gap h between the first electrode **112** and the second electrode **113** in a vertical direction (Z direction) ranges from −100 μm to 100 μm, preferably ranges from −100 μm to 10 μm, more preferably ranges from 0.5 μm to 10 μm.

According to the exemplary embodiment, the first electrode **112** on the first substrate **101***a* is a pixel electrode and is electrically connected to a pixel driving voltage. For details, the first electrode **112** (pixel electrode) is electrically connected to an active device T which is controlled by a scan line SL and a data line DL as shown in FIG. **3**A, and a driving voltage may be applied to the first electrode **112** (pixel electrode) through the active device T. The second electrode **113** on the second substrate **101***b* is a common electrode and is electrically connected to a common voltage Vcom. Because the first electrode **112** (pixel electrode) and the second electrode (common electrode) **113** have different voltages, a lateral electric field can be formed between the first electrode **112** (pixel electrode) and the second electrode **113** (common electrode). In particularly, the first electrode **112** (pixel electrode) and the second electrode **113** (common electrode) are respectively disposed on the first protrusion **110***a* and the second protrusion **110***b*, and the smallest vertical gap h between the first electrode **112** (pixel electrode) and the second electrode **113** (common electrode), is smaller than the cell gap and therefore the lateral electric field formed between the first electrode **112** (pixel electrode) and the second electrode **113** (common electrode) is stronger and the driving voltage can be reduced.

The display medium **130** is sandwiched between the first substrate **101***a* and the second substrate **101***b*. The display medium **130** comprises a blue phase liquid crystal (BPLC), polymer-stabilized BPLC composite, or any other liquid crystal that has an optically isotropic voltage-off state. In addition, a cell gap between the first substrate **101***a* and the second substrate **101***b*, which is also a thickness of the display medium **130** between the first substrate **101***a* and the second substrate **101***b*, is in a range from 2 μm to 100 μm.

In the exemplary embodiment of the display device, the display device further comprises a first polarizer **100***a*, a second polarizer **100***b* and at least one retardation film **120**. The first polarizer **100***a* and the second polarizer **100***b* are respectively disposed on outer surfaces of the first substrate **101***a* and the second substrate **101***b*. The first polarizer **100***a* and the second polarizer **100***b* may be linear or circular polarizers and can be made of dichroic polymer films, such as polyvinyl-alcohol-based film, and have their transmission axis perpendicular to each other or handedness opposite to each other.

The retardation film **120** is, for example, a biaxial film or uniaxial film, and is laminated between the polarizer **100***a* and the polarizer **100***b* to expand the viewing angle of the display device. The retardation film **120** could be a biaxial film with its Nz factor ($Nz=(nx-nz)/(nx-ny)$) at about 0.5 and in plane retardation $d\times(n_x-n_y)=\lambda/2$. Here n_x, n_y, and n_z denote the refractive indices of the biaxial film, d is the film thickness, and λ is the wavelength of interest. To achieve wide view, the n_x axis of the retardation film **120** is placed parallel to the absorption axis of the second polarizer **100***b*. In the exemplary embodiment, the in-plane phase retardation R**0**=d×(nx−ny) of the retardation film **120** is between 100 nm and 300 nm. The number of retardation films could be more than 1, and the retardation film **120** could be biaxial or uniaxial.

It is noted that the top view of the first electrode **112** and the second electrode **113** of FIG. **1** can be plotted in FIG. **3**A with lengthwise direction along the Y-axis in the XY plane. However, the patterns of the first electrode **112** and the second electrode **113** are not limited to FIG. **3**A. According to another exemplary embodiment, the first electrode **112** and second electrode **113** could also be in a zigzag shape in the XY plane as shown in FIG. **3**B to further expand the viewing angle symmetry. Besides, using said zigzag electrode structures could greatly reduce the color shift of the display device, as the dependence of azimuthal angles is also reduced.

FIG. **2** shows the voltage-dependent transmittance (VT) for the first exemplary embodiment. For comparison, the VT curve of a conventional IPS structure (the width of the electrode=2 μm, and the gap between the adjacent electrodes=4 μm) is also plotted (Curve **14**). Curve **15** is the VT curve for an example of the first exemplary embodiment with w**1**, w**2**=2 μm; l**1**, l**2**=10 μm; h**1**, h**2**=1.5 μm for the first and second protrusions **110***a*, **110***b* on the substrates **101***a*, **101***b*, and h=1.5 μm. In FIG. **2**, the on-voltage of curve **15** is significantly reduced comparing with that of the curve **14** of the conventional IPS structure.

Second Exemplary Embodiment

FIG. **4**A, FIG. **4**B and FIG. **4**C shows the schematic diagrams of a pixel structure of a LCD according to a second exemplary embodiment. As shown in FIG. **4**A, the display device includes a first substrate **101***a*, a plurality of first protrusions **110***a*, a first electrode **112**, a second electrode **113**, a plurality of second protrusions **110***b*, a third electrode **114**, a fourth electrode **115** and a display medium **130**. The embodiment depicted in FIG. **4**A is similar to the embodiment depicted in FIG. **1**, and the same components indicated in FIG. **4**A and FIG. **1** are denoted by the same numerals and are not repeated herein.

The first protrusions **110***a* are disposed on the first substrate **101***a*, and each first protrusion **110***a* has a first side wall S**1** and a second side wall S**2**. The second protrusions **110***b* are disposed on the second substrate **101***b*, and each second protrusion **110***b* has a third side wall S**3** and a fourth side wall S**4**. The widths of first and second protrusions w**1**, w**2** range from 0.2 μm~100 μm. The horizontal gaps **11**, **12** between adjacent first protrusions **110***a* and between adjacent second protrusions **110***b* range from 0.2 μm~100 μm. The thickness of first and second protrusions h**1**, h**2** could be from 0.2 μm to 100 μm. The first and second protrusions are separated by a vertical gap h which ranges from −100 μm~100 μm.

The first electrode **112** is on the first side wall S**1** of each first protrusion **110***a*, the second electrode **113** is on the second side wall S**2** of each first protrusion **110***a*, and a lateral electric field is formed between the first electrode **112** on the first side wall S**1** of each first protrusion **110***a* and the second electrode **113** on the second side wall S**2** of the adjacent first protrusion **110***a*. The third electrode **114** is disposed on the third side wall S**3** of each second protrusion **110***b*, the fourth electrode **115** is on the fourth side wall S**4** of each second protrusion **110***b*, and a lateral electric field is formed between the third electrode **114** on the third side wall S**3** of each second protrusion **110***b* and the fourth electrode **115** on the fourth side wall S**4** of the adjacent second protrusion **110***b*.

According to the embodiment, the first electrode **112** and the third electrode **114** are electrically connected to the same pixel driving voltage. For details, the first electrode **112** and the third electrode **114** are electrically connected to an active device which is controlled by a scan line and a data line, and a driving voltage may be applied to the first electrode **112** and the third electrode **114** through the active device. Therefore, the first electrode **112** and the third electrode **114** may also be referred to a pixel electrode. The first electrode **112** and the third electrode **114** can be directly connected to each other, or electrically connected to each other through a contact structure.

The second electrode **113** and the fourth electrode **115** are electrically connected to a common voltage. The second electrode **113** and the fourth electrode **115** can be directly connected to each other, or electrically connected to each other through a contact structure, or respectively electrically connected to the common voltage. Therefore, the second electrode **113** and the fourth electrode **115** may also be referred to a common electrode.

Because the first electrode **112** and the second electrode **113** have different voltages, a lateral electric field can be formed between the first electrode **112** and the second electrode **113**. Because the third electrode **114** and the fourth electrode **115** have different voltages, a lateral electric field can be formed between the third electrode **114** and the fourth electrode **115**. In particular, the lateral electric field formed between the first electrode **112** and the second electrode **113** is displaced in a horizontal direction with the lateral electric field formed between the third electrode **114** and the fourth electrode **115**, and therefore, more display medium **130** can be driven by the lateral electric fields so as to increase the transmittance of the display device.

In the exemplary embodiment, the display device may further comprises a first polarizer **100***a*, a second polarizer **100***b* and at least one retardation film **120**, and they are the same or similar to the first polarizer **100***a*, the second polarizer **100***b* and the retardation film **120** described in the first exemplary embodiment.

A similar structure is shown in FIG. **4**B, the different between the structure of FIG. **4**B and the structure of FIG. **4**A lies in that the positions of first electrode **112** and second electrode **113** are complementary. In FIG. **4**B, the first electrode **112** is aligned close to the fourth electrode **115**, and the second electrode **113** is aligned close to the third electrode **114**. However, in FIG. **4**A, the first electrode **112** is aligned close to the third electrode **114** and the second electrode **113** is aligned close to the fourth electrode **115** There could be some alignment tolerance in the embodiment.

FIG. **4**C depicts another example of the second exemplary embodiment, where the shape of the first protrusion **110***a* and the second protrusion **110***b* is trapezoid instead of rectangle. This shape is more likely to be formed in real fabrication. In addition, the definition of the other parameters is the same as in FIGS. **4**A and **4**B. In particular, the first protrusion **110***a* has a bottom width w**1**, a top width w**1'** and a thickness h**1** (as shown in FIG. **4**D), and the second protrusion **110***b* has a bottom width w**2**, a top width w**2'** and a thickness h**2** (as shown in FIG. **4**E). The widths w**1**, w**2** respectively range from 0.2 μm to 100 μm. The widths w**1'**, w**2'** are smaller than the widths w**1**, w**2**. The thicknesses h**1**, h**2** respectively range from 0.2 μm to 100 μm.

As FIGS. **4**A, **4**B and **4**C shown, the first protrusions **110***a* and the second protrusions **110***b* are complementarily aligned, so that the transmittance profile would be uniform along the X direction and a high averaged transmittance can be obtained. The shapes of the first and second protrusions

110*a*, **110***b* from the cross-sectional view are the same or different. There could be some horizontal shift of top and bottom protrusions.

FIG. **5** shows the voltage-dependent transmittance for the display devices of the second exemplary embodiment and a conventional display device with the IPS structure. Curve **19** and **20** are for the structure shown in FIG. **4**A, where the first and second protrusions are rectangular; and curve **21** is for the structure depicted in FIG. **4**C where the first and second protrusions are trapezoid. For comparison, the VT curve of a conventional display device with the IPS structure (the width of the electrode=2 μm, the space between the electrodes=2 μm) is also plotted (Curve **22**).

In the display device with the first and second rectangular protrusions (FIG. **4**A and FIG. **4**B), for w**1**, w**2**=2 μm; l**1**, l**2**=2 μm; h**1**, h**2**=3 μm, and h=1 μm, a peak transmittance of 99.5% is achieved at 6.6 V_{rms} as shown in curve **19**; for w**1**, w**2**=2 μm; l**1**, l**2**=2 μm; h**1**, h**2**=2 μm, and h=1 μm, a peak transmittance of 99.4% occurs at 7.8 V_{rms} as shown in curve **20**. The high transmittance is a result of uniform distributed transmittance profile all along the x direction, which is due to three main reasons. First, the pixel and common electrodes are formed on the steep sides of the rectangular protrusions, so that the electric fields induced between them are uniform. These areas are called effective regions. Second, the top and bottom substrates are aligned in such a way that the top and bottom effective regions could just compensate each other. Third, the width of the first and second protrusions is equal to the gap between the pixel electrode and the common electrode, so that the phase retardation along X direction remains uniform after superimposition. If the width of the first and second protrusions is larger than the horizontal gap between the pixel electrode and the common electrode, there would be some regions where the top and bottom protrusions overlap and create dead zones. On the other hand, if the width of the first and second protrusions is smaller than the horizontal gap between the pixel electrode and the common electrode, some regions accumulate phase retardation from both top and bottom effective regions, while the other regions only accumulate from one effective region. In both cases, peak transmittance cannot be obtained at different X locations simultaneously, and the non-uniform transmittance distribution along the X-direction leads to a lower average transmittance.

The low operating voltage relies on the following factors.

In these proposed structures, a larger thickness (h**1**, h**2**) leads to a more effective depth d_{eff} which in turn contributes to phase retardation $d_{eff}\Delta n(E)$. Thus the requirement for $\Delta n(E) \propto E^2$ is less stringent, and consequently smaller E field and voltage are needed to achieve the same phase retardation. As a result, operating voltage is significantly reduced. It is easy to derive that the operating voltage is approximately inversely proportional to the $(\text{thickness})^{1/2}$. Namely, the larger thickness is, the lower the operating voltage, meanwhile, the more difficult the fabrication would be.

In terms of operating voltage, the gap (l**1**, l**2**) plays a similar role as the thickness (h**1**, h**2**). From E=V/l, we know that the operating voltage is proportional to the gap (l**1**, l**2**). Namely, the smaller the gap (l**1**, l**2**) is, the lower the operating voltage.

Moreover, a structure with a larger thickness (h**1**, h**2**) tends to have a slightly higher transmittance as compared curve **19** with **20**. It is because the phase retardation is mainly contributed by the effective region right between the first protrusions (or the second protrusions) on the same side, but partially contributed by the gap region between first protrusion and second protrusion. The latter has an IPS like distribution of electric fields and phase retardation profile, which is not completely uniform along the X direction. The larger the ratio h/h**1** or h/h**2** is, the more this part would count in average transmittance, and reduce the transmittance by its non-uniform property. So larger thickness (h**1**, h**2**) would dilute this negative effect, and maintain the high transmittance. Meanwhile, the vertical gap h works in the opposite way, but its influence is not significant. When the vertical gap h=3 μm, the transmittance remains as high as 97.7% while the on-state voltage is still ~6.6 V_{rms}. Also this means it is not sensitive to the cell gap variation.

Curve **21** in FIG. **5** is the VT curve for the structure with the first and second trapezoid protrusions (as depicted in FIG. **4**C) where w**1**, w**2**=2 μm; w**1**', w**2**'=1 μm, l**1**, l**2**=2 μm; h**1**, h**2**=3 μm, and h=1 μm. The parameters are almost the same as those in curve **19** except that the first and second protrusions are now trapezoid. In this case, the electro-optical performance is still excellent with 95% transmittance and 7.2V_{rms} on-state voltage. The higher operating voltage is a result of a larger effective gap between the pixel electrode and the common electrode in the horizontal direction.

The protrusion shape is not limited to the rectangle, or trapezoid, but could be polygonal, semicircular or any other shape. The wall-shape structure is preferred due to its superior performance in both low driving voltage and extremely high transmittance. Trapezoid protrusion structure, which maintains a good performance, is very useful, because it is most likely to be formed in real fabrication. In all abovementioned cases, electrodes are coated on the steep walls of the protrusion, but they could be extended to the flat top of the protrusions.

Third Exemplary Embodiment

FIG. **6**A, FIG. **6**B and FIG. **6**C show the schematic diagrams of a pixel structure of a LCD according to a third exemplary embodiment. As shown in FIG. **6**A, the display device includes a first substrate **101***a*, a plurality of first protrusions **110***a*, a first electrode **112**, a second electrode **113**, a plurality of second protrusions **110***b*, a third electrode **114**, a fourth electrode **115** and a display medium **130**. The embodiment depicted in FIG. **6**A is similar to the embodiment depicted in FIG. **4**A, and the same components indicated in FIG. **6**A and FIG. **4**A are denoted by the same numerals and are not repeated herein.

In the FIG. **6**A, the first protrusions **110***a* are disposed on the first substrate **101***a*, and each first protrusion **110***a* has a first side S**1** wall and a second side wall S**2**. The second protrusions **110***b* are stacked on the first protrusions **110***a*, and each second protrusion **110***b* has a third side wall S**3** and a fourth side wall S**4**. The widths of first and second protrusions w**1**, w**2** range from 0.2 μm~100 μm. The horizontal gaps l**1**, l**2** between adjacent first protrusions **110***a* and between adjacent second protrusions **110***b* range from 0.2 μm~100 μm. The thicknesses h**1**, h**2** of the first and second protrusions could be from 0.2 μm to 100 μm.

The first electrode **112** is disposed on the first side wall S**1** of each first protrusion **110***a*, and the second electrode **113** is disposed on the second side wall S**2** of each first protrusion **110***a*. A lateral electric field is formed between the first electrode **112** on the first side wall S**1** of each first protrusion **110***a* and the second electrode **113** on the second side wall S**2** of the adjacent first protrusion **110***a*. The third electrode **114** is disposed on the third side wall S**3** of each second protrusion **110***b* and contacts with the first electrode **112** on the first protrusions **110***a*. The fourth electrode **115** is on the fourth side wall S**4** of each second protrusion **110***b* and contacts with the second electrode **113** on the first protrusions **110***a*. A lateral electric field is formed between the third electrode **114** on the third side wall S**3** of each second protrusion **110***b* and the fourth electrode **115** on the fourth side wall S**4** of the adjacent second protrusion **110***b*.

Similarly, the first electrode **112** and the third electrode **114** are electrically connected to the same pixel driving voltage, and thus the first electrode **112** and the third electrode **114** may also referred to a pixel electrode. For details, the first electrode **112** and the third electrode **114** are electrically connected to an active device which is controlled by a scan line and a data line, and a driving voltage may be applied to the first electrode **112** and the third electrode **114** through the active device. The second electrode **113** and the fourth electrode **115** are electrically connected to a common voltage, and thus the second electrode **113** and the fourth electrode **115** may also referred to a common electrode. Because the first electrode **112** and the second electrode **113** have different voltages, the lateral electric field can be formed between the first electrode **112** and the second electrode **113**. Because the third electrode **114** and the fourth electrode **115** have different voltages, the lateral electric field can be formed between the third electrode **114** and the fourth electrode **115**. In particular, the lateral electric field formed between the first electrode **112** and the second electrode **113** is complementary with the lateral electric field formed between the third electrode **114** and the fourth electrode **115**, and therefore, more display medium **130** can be driven by the lateral electric fields so as to increase the transmittance of the display device.

According to the embodiment, the first electrode **112** extends to the flat top of first protrusions **110***a* so as to electrically connect the first electrode **112** and the third electrode **114**. The second electrode **113** extends to the flat top of the first protrusions **110***a* so as to electrically connect the second electrode **113** and the fourth electrode **115**. In addition, the third electrode **114** and the fourth electrode **115** are not extended to the flat top of protrusions **110***b*, which are not limited by the disclosure.

In the exemplary embodiment, the display device may further comprise a first polarizer **100***a*, a second polarizer **100***b* and at least one retardation film **120**, and they are the same or similar to the first polarizer **100***a*, the second polarizer **100***b* and the retardation film **120** described in the first exemplary embodiment.

In such a structure, the transmittance in the spacing between the first protrusions **110***a* and that between the second protrusions **110***b* are very similar. Therefore, the uniformly distributed transmittance profile results in a high averaged transmittance. Because the pixel electrodes **114** and **112** are electrically connected and the common electrode **115** and **113** are electrically connected, one active device (thin film transistor) is needed, and aperture ratio and optical efficiency are improved.

A similar structure is shown in FIG. **6**B. The difference from the structure of FIG. **6**A lies in that the shape of the first protrusion **110***a* and the second protrusion **110***b* is trapezoid. FIG. **6**C depicts another example of the third exemplary embodiment, where the shape of the first protrusion **110***a* and the second protrusion **110***b* is rectangle, and the bottom width of the protrusions **110***b* is equal to the top width of the spacing between first protrusions **110***a*, as shown in FIG. **6**C. In addition, no extension for the pixel electrodes **112**, **114** and the common electrode **113**, **115** is needed, and thus a higher optical efficiency is obtained.

Fourth Exemplary Embodiment

FIG. **7**A and FIG. **7**B show the schematic diagrams of a pixel structure of a LCD according to a fourth exemplary embodiment. As shown in FIG. **7**A, the display device comprises a first substrate **101***a*, at least one first bump electrode **150**, a second substrate **101***b*, at least one second bump electrode **160**, and a display medium **130**. The embodiment depicted in FIG. **7**A is similar to the embodiment depicted in FIG. **1**, and the same components indicated in FIG. **7**A and FIG. **1** are denoted by the same numerals and are not repeated herein.

The first bump electrode **150** is disposed on the first substrate **101***a*. The second bump electrode **160** is disposed on the second substrate **101***b*, wherein the first bump electrode **150** and the second bump electrode **160** are displaced in a horizontal direction so as to form a lateral electric field therebetween. According to the embodiment, the first bump electrode **150** and the second bump electrode **160** are misaligned to each other in XY plane, and thus the first bump electrode **150** and the second bump electrode **160** are not overlapped to each other in XY plane. The first bump electrode **150** and the second bump electrode **160** can be made of a conductive polymer, for example. In addition, the first bump electrode **150** and the second bump electrode **160** may have the same or different shapes from the cross-sectional view. The thickness h**1** of the first bump electrode **150** and the thickness h**2** of the second bump electrode **160** could be from 0.2 μm to 20 μm. In particular, an overlapping height h' between the first bump electrode **150** and the second bump electrode **160** in the vertical direction (Z direction) is larger than 0 and smaller than a cell gap between the first substrate **101***a* and the second substrate **101***b*. In the embodiment, the cell gap between the first substrate **101***a* and the second substrate **101***b*, which is also a thickness of the display medium **130** between the first substrate **101***a* and the second substrate **101***b*, is in a range from 2 μm to 100 μm.

Moreover, the bottom width w**1** of the first bump electrode **150** and the bottom width w**2** of the second bump electrodes **160** may be the same or different, which respectively range from 0.2 μm to 100 μm. The top widths w**1**', w**2**' of the first bump electrode **150** and the second bump electrode **160** are smaller than the bottom widths w**1**, w**2**. The gap **11** between two adjacent first bump electrodes **150** on the first substrate **101***a* and the gap **12** between two adjacent second bump electrodes **160** on the second substrate **101***b* may respectively range from 0.2 μm to 100 μm.

According to the exemplary embodiment, the first bump electrode **150** on the first substrate **101***a* is a pixel electrode and is electrically connected to a pixel driving voltage. For details, the first bump electrode **150** (pixel electrode) is electrically connected to an active device which is controlled by a scan line and a data line, and a driving voltage may be applied to the first bump electrode **150** (pixel electrode) through the active device. The second bump electrode **160** on the second substrate **101***b* is a common electrode and is electrically connected to a common voltage. Because the first bump electrode **150** (pixel electrode) and the second bump electrode **160** (common electrode) have different voltages, a lateral electric field can be formed between the first bump electrode **150** (pixel electrode) and the second bump electrode **160** (common electrode). In particularly, the overlapping height h' between the first bump electrode **150** and the second bump electrode **160** in the vertical direction (Z direction) is larger than 0 and smaller than a cell gap between the first substrate **101***a* and the second substrate **101***b*, the lateral electric field formed between the first bump electrode **150** (pixel electrode) and the second bump electrode **160** (common electrode) is stronger and the driving voltage can be reduced.

In the exemplary embodiment, the display device may further comprises a first polarizer **100***a*, a second polarizer **100***b* and at least one retardation film **120**, and they are the same or similar to the first polarizer **100***a*, the second polarizer **100***b* and the retardation film **120** described in the first exemplary embodiment.

A similar structure is shown in FIG. **7**B, the different between the structure of FIG. **7**B and the structure of FIG. **7**A lies in that the first bump electrode **150** and the second bump electrode **160** respectively have a triangle shape. The shape of electrodes **150** and **160** are not limited to trapezoid or rectangle, but can be anything that fabrication allows.

FIG. **8** shows the VT curves of the pixel structure of the LCD in the fourth exemplary embodiment. Curve **17** and **18** are for the structure shown in FIG. **7**B. Curve **17** represents the VT curve for the display device with the first and second bump electrodes, wherein w**1**, w**2**=2 μm; l**1**, l**2**=6 μm; h**1**, h**2**=4 μm; and h'=1 μm. Curve **18** represents the VT curve for the display device with the first and second bump electrodes, wherein w**1**, w**2**=2 μm; l**1**, l**2**=6 μm; h**1**, h**2**=4 μm; and h'=2 μm. The driving voltage (on voltage) of the display device (curve **18**) is lower than the driving voltage (on voltage) of the display device (curve **17**).

It will be apparent to those skilled in the art that various modifications and variations can be made to the structure of the disclosed exemplary embodiments without departing from the scope or spirit of the disclosure. In view of the foregoing, it is intended that the disclosure cover modifications and variations of this disclosure provided they fall within the scope of the following claims and their equivalents.

What is claimed is:

1. A display device comprising:

a first substrate;

a plurality of first protrusions on the first substrate, each first protrusion having a first side wall and a second side wall;

a first electrode, on the first side wall of each first protrusion;

a second electrode, on the second side wall of each first protrusion, wherein a lateral electric field is formed between the first electrode on each first protrusion and the second electrode on the adjacent first protrusion;

a second substrate opposite to the first substrate;

a plurality of second protrusions on the second substrate, each second protrusion having a third side wall and a fourth side wall;

a third electrode, on the third side wall of each second protrusion;

a fourth electrode, on the fourth side wall of each second protrusion, wherein a lateral electric field is formed between the third electrode on each second protrusion and the fourth electrode on the adjacent second protrusion; and

a display medium sandwiched between the first and the second substrates.

2. The display device of claim **1**, wherein the first protrusions and the second protrusions are complementarily aligned.

3. The display device of claim **1**, wherein the first and second protrusions have a width ranged from 0.2 μm to 100 μm, the horizontal gaps between adjacent first protrusions and between adjacent second protrusions ranged from 0.2 μm to 100 μm, and thicknesses of the first and second protrusions ranged from 0.2 μm to 100 μm.

4. The display device of claim **1**, wherein shapes of the first and second protrusions from the cross-sectional view are the same or different.

5. The display device of claim **1**, wherein the first electrode is aligned to the third electrode in a vertical direction, and the second electrode is aligned to the fourth electrode in the vertical direction.

6. The display device of claim **1**, wherein the first electrode is aligned to the fourth electrode in a vertical direction, and the second electrode is aligned to the third electrode in the vertical direction.

7. The display device of claim **1**, wherein each first protrusion has a top surface and a bottom surface larger than the top surface, and each second protrusion has a top surface and a bottom surface larger than the top surface.

8. The display device of claim **1** further comprising:

a first linear or circular polarizer disposed on the first substrate;

a second linear or circular polarizer disposed on the second substrate; and

at least one retardation film disposed between the first and second linear or circular polarizers,

wherein the retardation film is a biaxial film with its Nz factor (Nz=(nx−nz)/(nx−ny)) at about 0.5, and the in-plane phase retardation R**0**=d×(nx−ny) between 100 nm and 300 nm.

9. The display device of claim **1**, wherein the display medium comprises a blue phase liquid crystal (BPLC), a polymer-stabilized BPLC composite or an optically isotropic liquid crystal composite.

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UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

Page 1 of 1

PATENT NO. : 8,736,800 B2
APPLICATION NO. : 13/348652
DATED : May 27, 2014
INVENTOR(S) : Yu-Pei Chang et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

On the title page, the item (73) Assignees
"University of Florida Research Foundation, Inc." should be changed to -- University of Central Florida Research Foundation, Inc. --.

Signed and Sealed this
Ninth Day of September, 2014

Michelle K. Lee

Michelle K. Lee
Deputy Director of the United States Patent and Trademark Office