

US Patent & Trademark Office

Patent Public Search | Text View

United States Patent	12396354
Kind Code	B2
Date of Patent	August 19, 2025
Inventor(s)	Tsuchiya; Hiroshi et al.

Display device

Abstract

A display device includes: a plurality of pixels arranged in a matrix in a display area, wherein each of the plurality of pixels includes a reflective liquid crystal portion and a self-luminous element portion, in the reflective liquid crystal portion, a first substrate does not include a switching element, a reflector, a pixel electrode, a liquid crystal layer, and an opposite electrode form a reflective liquid crystal display element that operates in bistable liquid crystal display mode, in the self-luminous element portion, the first substrate includes: a switching element; a self-luminous display element including a first electrode, an organic layer, and a second electrode; and a coating layer disposed on a side of the liquid crystal layer of the self-luminous display element, and the coating layer is provided contiguously across the reflective liquid crystal portion and the self-luminous element portion.

Inventors:	Tsuchiya; Hiroshi (Kameyama, JP), Satoh; Takashi (Kameyama, JP)
Applicant:	Sharp Display Technology Corporation (Kameyama, JP)
Family ID:	1000008767524
Assignee:	Sharp Display Technology Corporation (Kameyama, JP)
Appl. No.:	18/794409
Filed:	August 05, 2024

Prior Publication Data

Document Identifier	Publication Date
US 20250081800 A1	Mar. 06, 2025

Foreign Application Priority Data

JP	2023-139767	Aug. 30, 2023
----	-------------	---------------

Publication Classification

Int. Cl.: H10K59/50 (20230101); G02F1/1335 (20060101); G02F1/1337 (20060101); G02F1/139 (20060101); H10K59/131 (20230101)

U.S. Cl.:

CPC H10K59/50 (20230201); G02F1/133553 (20130101); G02F1/133746 (20210101); G02F1/133749 (20210101); G02F1/133769 (20210101); G02F1/1391 (20130101); G02F1/1397 (20130101); H10K59/131 (20230201); G02F2201/123 (20130101)

Field of Classification Search

CPC: H10K (59/50); H10K (59/131); G02F (1/133553); G02F (1/133746); G02F (1/133749); G02F (1/133769); G02F (1/1391); G02F (1/1397); G02F (2201/123); G02F (1/133616)

References Cited

U.S. PATENT DOCUMENTS

Patent No.	Issued Date	Patentee Name	U.S. Cl.	CPC
10547026	12/2019	Narutaki et al.	N/A	N/A
2003/0128314	12/2002	Dozov et al.	N/A	N/A
2005/0248705	12/2004	Smith et al.	N/A	N/A
2013/0194528	12/2012	Wang	313/504	H05B 33/14

FOREIGN PATENT DOCUMENTS

Patent No.	Application Date	Country	CPC
4530217	12/2009	JP	N/A
4942898	12/2011	JP	N/A

Primary Examiner: Raleigh; Donald L

Attorney, Agent or Firm: ScienBiziP, P.C.

Background/Summary

FIELD OF THE INVENTION

(1) The present disclosure relates to display devices.

BACKGROUND OF THE INVENTION

(2) Various display devices such as liquid crystal display devices and organic electroluminescence (EL) display devices have been used in many applications to display videos (moving images and still images).

(3) For instance, the liquid crystal display device is a display device that utilizes a liquid crystal composition to produce a display and in typical display techniques includes: a TFT substrate including thin film transistors (TFTs); an opposite substrate disposed opposite the TFT substrate; and a liquid crystal layer enclosed between the TFT substrate and the opposite substrate.

(4) Liquid crystal display devices are roughly divided into reflective types and transmissive types, depending on the technique by which light is transmitted to the liquid crystal layer. The reflective

liquid crystal display device includes a reflector inside the device and produces a display by reflecting incoming external incident light off the reflector so that the reflected light can be transmitted by the liquid crystal layer. The transmissive liquid crystal display device produces a display by a backlight unit, disposed on the rear side of the liquid crystal display device, outputting light that is transmitted by the liquid crystal layer. The reflective liquid crystal display device needs no backlight unit and therefore can achieve low power consumption, small thickness, and lightweight. In contrast, the transmissive liquid crystal display device includes a light source on the rear side of the device and therefore provides good visibility even in a dark environment.

(5) In addition, the organic EL display device is a self-luminous display device and includes, for example: a TFT substrate including TFTs; organic EL elements disposed on the TFT substrate and connected to the TFTs; and a sealing substrate disposed so as to cover the organic EL elements. Organic EL display devices for full-color display typically include three-color (red (R), green (G), and blue (B)) organic EL elements as subpixels. These subpixels are arranged in a matrix, and each set of three-color subpixels form a single pixel. Images are displayed by selectively causing these organic EL elements to emit light at desirable luminance.

(6) For example, as a technology related to a display device, Patent Literature 1 discloses, a display device including: a TFT substrate including drive elements and an insulating layer on the drive elements; a liquid crystal layer containing a liquid crystal composition; an opposite substrate including a transparent electrode, opposite the TFT substrate via the liquid crystal layer; and a polarizer provided on a surface of the opposite substrate opposite a surface of the opposite substrate facing the liquid crystal layer, wherein the display device includes, in a display area, a plurality of pixels each including a first region and a second region adjacent to each other, the first region includes a reflective electrode above the insulating layer of the TFT substrate, the second region includes a light-emitting element including a stack of a first electrode, an organic layer, and a second electrode on the insulating layer of the TFT substrate, the light-emitting elements includes a coating layer covering an entire light-emitting region of the individual pixels, and the coating layer has an edge thereof affixed to the insulating layer. As other examples, Patent Literature 2 and Patent Literature 3 also disclose a technology related to a display device.

CITATION LIST

Patent Literature

(7) Patent Literature 1: U.S. Pat. No. 10,547,026 Patent Literature 2: Japanese Patent No. 4530217
Patent Literature 3: Japanese Patent No. 4942898

SUMMARY OF THE INVENTION

Problems to Be Solved by the Invention

(8) FIG. **21** is a schematic cross-sectional view of a pixel in the display device of Patent Literature 1. Patent Literature 1 listed above discloses a hybrid display device that is a combination of reflective liquid crystal display elements and self-luminous display elements. Referring to FIG. **21**, a display device **1R** for hybrid display technique of Patent Literature 1 includes a reflective liquid crystal display element **20R** and a self-luminous display element **30R** in each pixel **1PR**, to improve outdoor visibility under direct sunlight and indoor and nighttime visibility.

(9) More specifically, the display device **1R** includes: a first substrate **100R** including an insulating film **105R** on thin film transistors (TFTs) as drive elements (switching elements) (specifically, current supply TFTs **12R** and switching TFTs **13R**); a liquid crystal layer **22R** containing liquid crystal molecules **22AR**; a second substrate **200R** including an opposite electrode **23R** and disposed opposite the first substrate **100R** via the liquid crystal layer **22R**; and a circular polarizer **25R** provided on a surface of the second substrate **200R** opposite a surface of the second substrate **200R** facing the liquid crystal layer **22R**.

(10) The display device **1R** includes a plurality of pixels **1PR** each including a reflective liquid crystal portion **1AR** and a self-luminous element portion **1BR** disposed adjacent to each other in the display area.

(11) In the reflective liquid crystal portion **1AR**, the first substrate **100R** includes: a first support substrate **101R**; a source electrode **13SR**, a semiconductor layer **102AR**, and a drain electrode **13DR**; a gate insulating film **103R**; a gate electrode **13GR**; an inorganic insulating film **104R**; the insulating film **105R**; a liquid-crystal-element-side insulating film **32aR**; and a reflective electrode **21R**, which are stacked in the stated order toward the liquid crystal layer **22R** side. The source electrode **13SR**, the gate electrode **13GR**, the drain electrode **13DR**, and the semiconductor layer **102AR** form the switching TFT **13R**. The reflective electrode **21R**, the liquid crystal layer **22R**, the opposite electrode **23R**, and the circular polarizer **25R** provided in the reflective liquid crystal portion **1AR** form the reflective liquid crystal display element **20R**.

(12) In the self-luminous element portion **1BR**, the first substrate **100R** includes: the first support substrate **101R**; a source electrode **12SR**, a semiconductor layer **102BR**, and a drain electrode **12DR**; the gate insulating film **103R**; a gate electrode **12GR**; the inorganic insulating film **104R**; the insulating film **105R**; a first electrode **31R**; a self-luminous-element-side insulating film **32R**; an organic layer **33R**; a second electrode **34R**; and a coating layer **35R**, which are stacked in the stated order toward the liquid crystal layer **22R** side. The source electrode **12SR**, the gate electrode **12GR**, the drain electrode **12DR**, and the semiconductor layer **102BR** form the current supply TFT **12R**. The first electrode **31R**, the organic layer **33R**, and the second electrode **34R** form the self-luminous display element **30R**. The coating layer **35R** covers the entire self-luminous display element **30R** for each pixel **1PR** and may be referred to as a sealing layer.

(13) The self-luminous-element-side insulating film **32R** is an insulating film that is often referred to as an insulating bank for delimiting light-emitting regions. The self-luminous-element-side insulating film **32R** is provided also on the insulating film **105R** of the reflective liquid crystal portion **1AR** and is made of the same material and with generally the same thickness. The self-luminous-element-side insulating film **32R** in the reflective liquid crystal portion **1AR**, since being separated from the self-luminous-element-side insulating film **32R**, which is a so-called insulating bank, of the self-luminous element portion **1BR**, is referred to as the liquid-crystal-element-side insulating film **32aR**.

(14) The second substrate **200R** including a second support substrate **201R**, a color filter layer **24R**, and the opposite electrode **23R**, which are stacked in the stated order toward the liquid crystal layer **22R** side.

(15) The reflective liquid crystal display element **20R** has either a TFT drive structure or a memory-in-pixel (MIP) structure. Either the switching TFT **13R** or a memory circuit, provided in the same layer as the drive circuit (current supply TFT **12R**) disposed in the self-luminous element portion **1BR**, needs to be connected to the reflective electrode **21R**.

(16) In the display device **1R**, to connect the reflective electrode **21R** and the switching TFT **13R** provided in the reflective liquid crystal portion **1AR**, the coating layer **35R** is not provided in the reflective liquid crystal portion **1AR**, only the self-luminous display element **30R** needs to be sealed by the coating layer **35R**, and in the reflective liquid crystal portion **1AR**, there needs to be provided a contact hole **11CHR** in the liquid-crystal-element-side insulating film **32aR** disposed in a lower part of the reflective electrode **21R**. In so doing, since the coating layer **35R** is formed in an insular shape, a boundary is formed in the coating layer **35R** in each pixel **1PR**, and, for example, moisture may penetrate through this boundary, which could degrade the self-luminous display element **30R**. As described here, in the display device **1R**, the self-luminous display element **30R** is not sufficiently sealed and may have a short lifespan.

(17) The present invention, made in view of these issues, has an object to provide a display device that includes a reflective liquid crystal display element and a self-luminous display element in each pixel and that restrains degradation of the self-luminous display element.

Solution to the Problems

(18) (1) The present invention, in an embodiment thereof, is directed to a display device including: a first substrate including a switching element; a liquid crystal layer containing liquid crystal

molecules; and a second substrate including an opposite electrode, all of which are provided sequentially, the display device further including a plurality of pixels arranged in a matrix in a display area, wherein each of the plurality of pixels includes a reflective liquid crystal portion and a self-luminous element portion, in the reflective liquid crystal portion, the first substrate includes a reflector, a coating layer, and a pixel electrode, which are provided sequentially toward a liquid crystal layer side, but does not include a switching element, the reflector, the pixel electrode, the liquid crystal layer, and the opposite electrode form a reflective liquid crystal display element that operates in bistable liquid crystal display mode, in the self-luminous element portion, the first substrate includes: the switching element; a self-luminous display element including a first electrode, an organic layer, and a second electrode; and the coating layer disposed on a liquid crystal layer side of the self-luminous display element, and the coating layer is provided contiguously across the reflective liquid crystal portion and the self-luminous element portion.

(19) (2) The present invention, in another embodiment thereof, is directed to a display device of (1) described above that is further configured so as to further include: a non-display area provided around the display area; and a wire provided in the non-display area of the first substrate, wherein in the non-display area, the opposite electrode is connected to the wire, and the pixel electrode is connected to the wire.

(20) (3) The present invention, in another embodiment thereof, is directed to a display device of (1) or (2) described above that is further configured such that the liquid crystal layer assumes either one of a first stable state and a second stable state in which the liquid crystal molecules assume different alignment states in absence of applied voltage where a voltage that is lower than a threshold value is applied across the pixel electrode and the opposite electrode, and the liquid crystal molecules are switched between the first stable state and the second stable state by applying a pulsed voltage across the pixel electrode and the opposite electrode.

(21) (4) The present invention, in another embodiment thereof, is directed to a display device of (1), (2), or (3) described above that is further configured such that the coating layer is provided contiguously across the plurality of pixels.

(22) (5) The present invention, in another embodiment thereof, is directed to a display device of (1), (2), (3), or (4) described above that is further configured such that the reflector is disposed in a same layer as the first electrode.

(23) (6) The present invention, in another embodiment thereof, is directed to a display device of (1), (2), (3), (4), or (5) described above that is further configured so as to further include: a vertical alignment film disposed between the first substrate and the liquid crystal layer; and a grating layer disposed between the second substrate and the liquid crystal layer, wherein the liquid crystal layer assumes either one of a first stable state in which the liquid crystal molecules assume a vertical alignment and a second stable state in which the liquid crystal molecules assume an HAN alignment in absence of applied voltage where a voltage that is lower than a threshold value is applied across the pixel electrode and the opposite electrode, and the liquid crystal molecules are switched between the first stable state and the second stable state by applying a pulsed voltage across the pixel electrode and the opposite electrode.

(24) (7) The present invention, in another embodiment thereof, is directed to a display device of (6) described above that is further configured such that in the first stable state, the liquid crystal molecules have a pretilt angle of from 85° to 90° , both inclusive, on a first substrate side and a pretilt angle of from 85° to 90° , both inclusive, on a second substrate side.

(25) (8) The present invention, in another embodiment thereof, is directed to a display device of, (6) or (7) described above that is further configured such that in the second stable state, the liquid crystal molecules have a pretilt angle of from 85° to 90° , both inclusive, on a first substrate side and a pretilt angle of from 0° to 5° , both inclusive, on a second substrate side.

(26) (9) The present invention, in another embodiment thereof, is directed to a display device of (1), (2), (3), (4), or (5) described above that is further configured so as to further include: a pretilted

horizontal alignment film disposed between the first substrate and the liquid crystal layer; and a grating layer disposed between the second substrate and the liquid crystal layer, wherein the liquid crystal layer assumes either one of a first stable state in which the liquid crystal molecules assume a TN alignment and a second stable state in which the liquid crystal molecules assume an HAN alignment in absence of applied voltage where a voltage that is lower than a threshold value is applied across the pixel electrode and the opposite electrode, and the liquid crystal molecules are switched between the first stable state and the second stable state by applying a pulsed voltage across the pixel electrode and the opposite electrode.

(27) (10) The present invention, in another embodiment thereof, is directed to a display device of (9) described above that is further configured such that in the first stable state, the liquid crystal molecules have a pretilt angle of from 3° to 5° , both inclusive, on a first substrate side and a pretilt angle of from 0° to 5° , both inclusive, on a second substrate side, and an alignment direction of the liquid crystal molecules on the first substrate side and an alignment direction of the liquid crystal molecules on the second substrate side make an angle of from 80° to 90° , both inclusive, in a plan view.

(28) (11) The present invention, in another embodiment thereof, is directed to a display device of (9) or (10) described above that is further configured such that in the second stable state, the liquid crystal molecules have a pretilt angle of from 3° to 5° , both inclusive, on a first substrate side and a pretilt angle of from 85° to 90° , both inclusive, on a second substrate side.

(29) (12) The present invention, in another embodiment thereof, is directed to a display device of (1), (2), (3), (4), or (5) described above that is further configured so as to further include: a weak anchoring alignment film disposed between the first substrate and the liquid crystal layer; and a strong anchoring alignment film disposed between the second substrate and the liquid crystal layer, wherein the liquid crystal layer assumes either one of a first stable state in which the liquid crystal molecules assume a homogeneous alignment and a second stable state in which the liquid crystal molecules on a first substrate side assume a twisted alignment in which these liquid crystal molecules are twisted by 180° from the first stable state in a plan view, in absence of applied voltage where a voltage that is lower than a threshold value is applied across the pixel electrode and the opposite electrode, and the liquid crystal molecules are switched between the first stable state and the second stable state by applying a pulsed voltage across the pixel electrode and the opposite electrode.

(30) (13) The present invention, in another embodiment thereof, is directed to a display device of (12) described above that is further configured such that in the first stable state, the liquid crystal molecules have a pretilt angle of from 0° to 5° , both inclusive, on the first substrate side and a pretilt angle of from 5° to 10° , both inclusive, on a second substrate side, and an alignment direction of the liquid crystal molecules on the first substrate side and an alignment direction of the liquid crystal molecules on the second substrate side make an angle of from 0° to 10° , both inclusive, in a plan view.

(31) (14) The present invention, in another embodiment thereof, is directed to a display device of (12) or (13) described above that is further configured such that in the second stable state, the liquid crystal molecules have a pretilt angle of from 0° to 5° , both inclusive, on the first substrate side and a pretilt angle of from 5° to 10° , both inclusive, on a second substrate side, an alignment direction of the liquid crystal molecules on the first substrate side and an alignment direction of the liquid crystal molecules on the second substrate side make an angle of from 0° to 10° , both inclusive, in a plan view, and the liquid crystal molecules are aligned twisted in-plane by from 170° to 180° , both inclusive, from the first substrate side toward the second substrate side.

(32) (15) The present invention, in another embodiment thereof, is directed to a display device of (1), (2), (3), (4), (5), (6), (7), (8), (9), (10), (11), (12), (13) or (14) described above that is further configured such that the reflector has projections and depressions on a surface of the reflector on the liquid crystal layer side.

(33) The present invention can provide a display device that includes a reflective liquid crystal display element and a self-luminous display element in each pixel and that restrains degradation of the self-luminous display element.

Description

BRIEF DESCRIPTION OF DRAWINGS

- (1) FIG. 1 is a schematic cross-sectional view of a pixel in a display device in accordance with Embodiment 1.
- (2) FIG. 2A is a schematic plan view of the display device in accordance with Embodiment 1.
- (3) FIG. 2B is a schematic enlarged plan view of a region surrounded by a broken line shown in FIG. 2A.
- (4) FIG. 3 is an equivalent circuit diagram of, for example, a TFT and wires disposed on a first substrate shown in FIG. 1.
- (5) FIG. 4 is a schematic cross-sectional view of a contact between an opposite electrode and a wire in a non-display area of the display device in accordance with Embodiment 1.
- (6) FIG. 5 is a schematic cross-sectional view of a contact between a pixel electrode and a wire in the non-display area of the display device in accordance with Embodiment 1.
- (7) FIG. 6 is a schematic cross-sectional view of liquid crystal molecules in the display device in accordance with Embodiment 1 in a homeotropic alignment.
- (8) FIG. 7 is a diagram representing a first pulse waveform of a voltage applied across the pixel electrode and the opposite electrode in the display device in accordance with Embodiment 1.
- (9) FIG. 8 is a schematic cross-sectional view of liquid crystal molecules in the display device in accordance with Embodiment 1 in an HAN alignment.
- (10) FIG. 9 is a diagram representing a second pulse waveform of the voltage applied across the pixel electrode and the opposite electrode in the display device in accordance with Embodiment 1.
- (11) FIG. 10 is a schematic cross-sectional view of a pixel in a display device in accordance with Embodiment 2.
- (12) FIG. 11 is a schematic cross-sectional view of liquid crystal molecules in the display device in accordance with Embodiment 2 in a TN alignment.
- (13) FIG. 12 is a diagram representing a first pulse waveform of a voltage applied across a pixel electrode and an opposite electrode in the display device in accordance with Embodiment 2.
- (14) FIG. 13 is a schematic cross-sectional view of liquid crystal molecules in the display device in accordance with Embodiment 2 in an HAN alignment.
- (15) FIG. 14 is a diagram representing a second pulse waveform of the voltage applied across the pixel electrode and the opposite electrode in the display device in accordance with Embodiment 2.
- (16) FIG. 15 is a schematic cross-sectional view of a pixel in a display device in accordance with Embodiment 3.
- (17) FIG. 16 is a schematic cross-sectional view of liquid crystal molecules in the display device in accordance with Embodiment 3 in a homogeneous alignment.
- (18) FIG. 17 is a diagram representing a first pulse waveform of a voltage applied across a pixel electrode and an opposite electrode in the display device in accordance with Embodiment 3.
- (19) FIG. 18 is a schematic cross-sectional view of liquid crystal molecules in the display device in accordance with Embodiment 3 in a twisted alignment.
- (20) FIG. 19 is a diagram representing a second pulse waveform of the voltage applied across the pixel electrode and the opposite electrode in the display device in accordance with Embodiment 3.
- (21) FIG. 20 is a schematic cross-sectional view of a pixel in a display device in accordance with Embodiment 4.

(22) FIG. 21 a schematic cross-sectional view of a pixel in a display device in accordance with Patent Literature 1.

DESCRIPTION OF EMBODIMENTS

(23) The following will describe embodiments of the present invention. The present invention is not limited to the content of the description of the following embodiments and may be appropriately changed in design without departing from the technical concept of the present invention. Note that throughout the following description, identical members and those having similar functions are indicated by the same reference numerals in different drawings where appropriate, and description of such members may not be repeated. Various embodiments of the present invention may be combined in a suitable manner without departing from its spirit of the present invention.

Embodiment 1

(24) FIG. 1 is a schematic cross-sectional view of a pixel in a display device in accordance with Embodiment 1. FIG. 2A is a schematic plan view of the display device in accordance with Embodiment 1. FIG. 2B is a schematic enlarged plan view of a region surrounded by a broken line shown in FIG. 2A. FIG. 3 is an equivalent circuit diagram of, for example, a TFT and wires disposed on a first substrate shown in FIG. 1.

(25) Referring to FIGS. 1 to 3, a display device 1 in accordance with the present embodiment includes: a first substrate 100 including switching elements; a liquid crystal layer 22 containing liquid crystal molecules 22A; and a second substrate 200 including an opposite electrode 23, which are stacked in the stated order. The display device 1 includes a plurality of pixels 1P arranged in a matrix in a display area 10A. Each pixel 1P includes a reflective liquid crystal portion 1A and a self-luminous element portion 1B. In the reflective liquid crystal portion 1A, the first substrate 100 includes a reflector 21X, a coating layer 35, and a pixel electrode 21, which are stacked in the stated order toward the liquid crystal layer 22 side, and includes no switching elements. The reflector 21X, the pixel electrode 21, the liquid crystal layer 22, and the opposite electrode 23 form a reflective liquid crystal display element 20 that operates in bistable liquid crystal display mode. In the self-luminous element portion 1B, the first substrate 100 includes: current-supply thin film transistors (TFTs) 12 as the switching elements; self-luminous display elements 30 each including a first electrode 31, an organic layer 33, and a second electrode 34; and the coating layer 35 disposed on the liquid crystal layer 22 side of the self-luminous display element 30. The coating layer 35 is provided contiguously across the reflective liquid crystal portion 1A and the self-luminous element portion 1B.

(26) The reflector 21X, the pixel electrode 21, the liquid crystal layer 22, and the opposite electrode 23, disposed in the reflective liquid crystal portion 1A, form the reflective liquid crystal display element 20 that operates in bistable liquid crystal display mode. The self-luminous display element 30 is disposed in the self-luminous element portion 1B. As described here, the display device 1 in accordance with the present embodiment is a hybrid display device that is a combination of the reflective liquid crystal display elements 20 and the self-luminous display elements 30 and enables improving outdoor visibility under direct sunlight and indoor and nighttime visibility.

(27) Here, as shown in FIG. 21, in Patent Literature 1 described above, the reflective liquid crystal display element 20R disposed in the reflective liquid crystal portion 1AR is an active matrix drive type, and to connect the reflective electrode 21R and the switching TFT 13R in the reflective liquid crystal portion 1AR, the coating layer 35R is not provided in the reflective liquid crystal portion 1AR and needs to be provided insularly only in the self-luminous element portion 1BR where the self-luminous display element 30R is disposed. As a result, a boundary is formed between the insulating film 105R and the coating layer 35R in each pixel 1PR, and, for example, moisture may penetrate through this boundary, which could degrade the self-luminous display element 30R.

(28) In contrast, in the present embodiment, the reflective liquid crystal display element 20 operates in bistable liquid crystal display mode and therefore can be passively driven irrespective of

resolution, which eliminates the need for active elements (switching elements) such as TFTs. In the display device **1** in accordance with the present embodiment, there is no need to provide TFTs in the reflective liquid crystal portion **1A** where the reflective liquid crystal display elements **20** are provided. Therefore, there is no need to connect the pixel electrodes to the TFTs in the reflective liquid crystal portion as in Patent Literature 1 described above. The coating layer **35** can be hence provided contiguously across the reflective liquid crystal portion **1A** and the self-luminous element portion **1B**. As a result, for example, water can be restrained from penetrating through the boundary in the coating layer **35**, which in turn enables restraining degradation of the self-luminous display element **30**.

(29) As described here, the present embodiment enables passive drive by adopting bistable liquid crystal display mode as the display mode of the reflective liquid crystal display element **20**. As a result, the coating layer **35** no longer needs to be provided only in the self-luminous element portion **1B** where the self-luminous display element **30** is disposed, for contacts between the pixel electrode and the TFTs. For example, the entire panel surface may be sealed all together. This eliminates the in-plane boundary in the coating layer **35** from the panel, thereby restraining, for example, penetration of moisture and in turn restraining degradation of the self-luminous display element **30**. The following will describe the present embodiment in detail.

(30) Referring to FIG. 2A, the display device **1** has: the display area (active area) **10A** where images can be displayed; and a non-display area (non-active area) **10B**, surrounding the display area **10A**, where no images can be displayed. The non-display area **10B** includes: a first non-display area portion **10B1** disposed on the display area **10A** side; and a second non-display area portion **10B2** disposed outside the first non-display area portion **10B1**. The first non-display area portion **10B1** includes a black matrix layer **24X** and can therefore realize a black frame. The second non-display area portion **10B2** includes no black matrix layer.

(31) Referring to FIG. 2B, the display device **1** includes, for example: a row electrode **21P** arranged in the row direction and connected to a row electrode signal wire **21PL**; and a column electrode **23P** arranged in the column direction and connected to a column electrode signal wire **23PL**. The row electrode **21P** and the row electrode signal wire **21PL** are connected in a region overlapping the black matrix layer **24X** in a plan view. The column electrode **23P** and the column electrode signal wire **23PL** are connected in a region overlapping the black matrix layer **24X** in a plan view. The row electrode **21P** corresponds to the pixel electrode **21**, and the column electrode **23P** corresponds to the opposite electrode **23**. In addition, the row electrode signal wire **21PL** and the column electrode signal wire **23PL** correspond to a wire **330** (detailed later).

(32) The display device **1** includes the plurality of pixels **1P** arranged in a matrix in the display area **10A**, and each of the plurality of pixels **1P** includes the reflective liquid crystal portion **1A** and the self-luminous element portion **1B**. The reflective liquid crystal portion **1A** and the self-luminous element portion **1B** are disposed adjacent to each other in a plan view. A “pixel” is a minimum unit of a display image. The display device **1** may be, for example, either a black and white display device or a color display device. When the display device **1** is a color display device, the pixels **1P** may be subpixels. In the current context, a “subpixel” refers to each monochromatic (generally, of a primary color) region in pixels that form a color display image.

(33) The display device **1** further includes a flexible printed circuit (FPC) **10C** provided in the non-display area **10B** and electrically connected to the first substrate **100**. The FPC **10C** is a flexible printed board and electrically connects the first substrate **100** to an external (host) control circuit board that is a signal supply source.

(34) The display device **1** has, for example, a polygonal profile as shown in FIG. 2A. The FPC **10C** may be provided on one of the sides of the polygon. This polygonal display device **1** may be used as a module for a smart watch.

(35) Referring to FIG. 1, the display device **1** in accordance with the present embodiment includes: the first substrate **100** including the current supply TFTs **12** as the switching elements; the liquid

crystal layer **22** containing the liquid crystal molecules **22A**; and the second substrate **200** including the opposite electrode **23**, which are stacked in the stated order.

(36) In the reflective liquid crystal portion **1A**, the first substrate **100** includes a first support substrate **101**, a gate insulating film **103**, an inorganic insulating film **104**, an insulating film **105**, the reflector **21X**, the coating layer **35**, and the pixel electrode **21**, which are stacked in the stated order toward the liquid crystal layer **22** side. In the self-luminous element portion **1B**, the first substrate **100** includes: the first support substrate **101**; a source electrode **12S**, a semiconductor layer **102**, and a drain electrode **12D**; the gate insulating film **103**; a gate electrode **12G**; the inorganic insulating film **104**; the insulating film **105**; the first electrode **31**; a self-luminous-element-side insulating film **32**; the organic layer **33**; the second electrode **34**; and the coating layer **35**, which are stacked in the stated order toward the liquid crystal layer **22** side.

(37) The source electrode **12S**, the gate electrode **12G**, the drain electrode **12D**, and the semiconductor layer **102** form the current supply TFT **12**. The first electrode **31**, the organic layer **33**, and the second electrode **34** form the self-luminous display element **30**. The self-luminous display element **30** is covered by the coating layer **35**. The first electrode **31** is, for example, an anode. The organic layer **33** is, for example, an organic light-emitting diode (OLED) layer. The second electrode **34** is, for example, a cathode. The self-luminous display element **30** is, for example, an organic electroluminescence (EL) display element.

(38) The second substrate **200** includes a second support substrate **201**, a color filter layer **24**, and the opposite electrode **23**, which are stacked in the stated order toward the liquid crystal layer **22** side. There is provided a circular polarizer **25** on a face of the second substrate **200** opposite the liquid crystal layer **22**.

(39) The reflector **21X**, the pixel electrode **21**, the liquid crystal layer **22**, and the opposite electrode **23**, disposed in the reflective liquid crystal portion **1A**, form the reflective liquid crystal display element **20** that operates in bistable liquid crystal display mode. Bistable liquid crystal display elements may be designed, for example, as in Japanese Patent No. 4530217 and Japanese Patent No. 4942898, which are published Japanese Patents. The present embodiment incorporates herein by reference the entire content of Japanese Patent No. 4530217 and Japanese Patent No. 4942898.

(40) In the present embodiment, contact between the switching element and the pixel electrode in the reflective liquid crystal portion can be eliminated by separating the reflective electrode **21R** used in Patent Literature 1 described above into the pixel electrode **21** and the reflector **21X**. Furthermore, in the present embodiment, by separating the reflective electrode **21R** into the pixel electrode **21** and the reflector **21X**, the pixel electrode **21** between adjacent pixels does not need to be separated, which enables passive matrix drive.

(41) FIG. 4 is a schematic cross-sectional view of a contact between an opposite electrode and a wire in a non-display area of the display device in accordance with Embodiment 1. FIG. 5 is a schematic cross-sectional view of a contact between a pixel electrode and a wire in the non-display area of the display device in accordance with Embodiment 1. Referring to FIGS. 4 and 5, the first substrate **100** and the second substrate **200** are adhered together, but separated by a gap owing to a seal **310** provided on a periphery (non-display area **10B**). The liquid crystal molecules **22A** are tightly sealed in the gap, forming the liquid crystal layer **22**. The seal **310** is mixed with spherical spacers **320** that have a gold-coated surface. Referring to FIG. 4, the display device **1** has: the non-display area **10B** provided around the display area **10A**; and the wire **330** provided in the non-display area **10B** of the first substrate **100**. The opposite electrode **23** and the wire **330** are connected in the non-display area **10B**. In addition, referring to FIG. 5, the pixel electrode **21** and the wire **330** are connected in the non-display area **10B**. Both connecting portions are located outside the TFE (coating layer **35**), and there is no need to provide contact holes in, for example, the TFE and various insulating layers for the connection. The wire **330** is connected via the FPC **10C** to an external (host) control circuit board that is a signal supply source.

(42) The liquid crystal layer **22** contains the liquid crystal molecules **22A**. It is difficult to provide

the liquid crystal layer **22** only in the reflective liquid crystal portion **1A** and is provided across the entire face including the self-luminous element portion **1B** as well as the opposite electrode **23**. In the liquid crystal layer **22**, the liquid crystal molecules **22A** are aligned in such a manner as to assume either one of a first stable state and a second stable state, which differ from each other, in the absence of applied voltage where a voltage that is lower than a threshold value is applied across the pixel electrode **21** and the opposite electrode **23**. The liquid crystal molecules **22A** are switched between the first stable state and the second stable state by applying a pulsed voltage across the pixel electrode **21** and the opposite electrode **23**. Although a pulsed voltage is applied across the pixel electrode **21** and the opposite electrode **23** in switching between the first stable state and the second stable state, there is no need to continuously apply the voltage to maintain the first stable state and the second stable state. Note that the “absence of applied voltage” includes zero voltage being applied across the pixel electrode **21** and the opposite electrode **23**.

(43) The liquid crystal molecules **22A** are liquid crystal molecules in which the dielectric anisotropy ($\Delta\epsilon$), defined by following equation (L), has either a positive value or a negative value. The liquid crystal molecules with positive dielectric anisotropy are also referred to as a positive liquid crystal, and the liquid crystal molecules with negative dielectric anisotropy are also referred to as a negative liquid crystal. The direction of the major axis of the liquid crystal molecules matches with the direction of the slow axis. The liquid crystal molecules **22A** in accordance with the present embodiment are preferably a positive liquid crystal.

$\Delta\epsilon = (\text{Permittivity of liquid crystal molecules along major axis}) - (\text{Permittivity of liquid crystal molecules along minor axis})$ (L)

(44) The display device **1** includes: a vertical alignment film **41** disposed between the first substrate **100** and the liquid crystal layer **22**; and a grating layer **42** disposed between the second substrate **200** and the liquid crystal layer **22**. The liquid crystal layer **22** assumes either one of the first stable state in which the liquid crystal molecules **22A** are vertically aligned and the second stable state in which the liquid crystal molecules **22A** assumes HAN (Hybrid Aligned Nematic) alignment in the absence of applied voltage where a voltage that is lower than a threshold value is applied across the pixel electrode **21** and the opposite electrode **23**. The liquid crystal molecules **22A** are switched between the first stable state and the second stable state by applying a pulsed voltage across the pixel electrode **21** and the opposite electrode **23**. The alignment of the liquid crystal molecules **22A** in the first stable state is alternatively referred to as the initial alignment. In other words, the initial alignment of the liquid crystal molecules **22A** in accordance with the present embodiment is a vertical alignment. In the present embodiment, the circular polarizer **25** is set up in such a manner that the display device **1** can produce a black display in the first stable state (vertical alignment). In the present embodiment, the display device **1** produces a white display in the second stable state (HAN alignment).

(45) The liquid crystal molecules **22A** switch from the first stable state to the second stable state upon the application of a prescribed pulse voltage (voltage that has a first pulse waveform) across the pixel electrode **21** and the opposite electrode **23**, whereby the liquid crystal molecules **22A** on the grating layer **42** side change their alignment to an HAN alignment. In addition, the liquid crystal molecules **22A** switch from the second stable state to the first stable state upon the application of a prescribed pulse voltage (voltage that has a second pulse waveform) across the pixel electrode **21** and the opposite electrode **23**, whereby the liquid crystal molecules **22A** on the grating layer **42** side change their alignment to a vertical alignment. A voltage needs to be applied only when the alignment is to be changed, and there is no need to maintain the voltage. This bistable liquid crystal display mode is alternatively referred to as “ZBD (zenithal bistable display).” Further detail is given below.

(46) FIG. **6** is a schematic cross-sectional view of liquid crystal molecules in the display device in accordance with Embodiment 1 in a homeotropic alignment. FIG. **7** is a diagram representing the first pulse waveform of the voltage applied across the pixel electrode and the opposite electrode in

the display device in accordance with Embodiment 1. FIG. 8 is a schematic cross-sectional view of liquid crystal molecules in the display device in accordance with Embodiment 1 in an HAN alignment. FIG. 9 is a diagram representing a second pulse waveform of the voltage applied across the pixel electrode and the opposite electrode in the display device in accordance with Embodiment 1. FIG. 6 represents the initial alignment state, in other words, the first stable state. FIG. 8 represents the second stable state.

(47) In the first stable state, the liquid crystal molecules 22A are in a homeotropic alignment (vertical alignment), as shown in FIG. 6, between the vertical alignment film 41 disposed on the first substrate 100 side and the grating layer 42 disposed on the second substrate 200 side. At this stage, if the pulsed voltage shown in FIG. 7 is applied across the pixel electrode 21 on the first substrate 100 side and the opposite electrode 23 on the second substrate 200 side, the liquid crystal molecules 22A on the grating layer 42 side are released from anchoring and rotate in the plane of the drawing (FIG. 6). The rotated liquid crystal molecules 22A are realigned to the second stable state, assuming the HAN alignment shown in FIG. 8.

(48) In the HAN alignment state shown in FIG. 8, if a voltage that has the pulse waveform shown in FIG. 9 is applied across the pixel electrode 21 and the opposite electrode 23, the liquid crystal molecules 22A on the grating layer 42 side are released from anchoring and rotate in the plane of the drawing (FIG. 8). The rotated liquid crystal molecules 22A are realigned to the first stable state, assuming the homeotropic alignment shown in FIG. 6.

(49) Although there is a need to apply a pulsed voltage for switching between the first stable state shown in FIG. 6 and the second stable state shown in FIG. 8, there is no need to continuously apply the voltage across the pixel electrode 21 and the opposite electrode 23 to maintain the two stable states because both the first stable state and the second stable state are energetically stable states.

(50) The vertical alignment film 41 is provided across the entire face of the display area 10A. The vertical alignment film has a function of aligning the liquid crystal molecules in the liquid crystal layer vertically with respect to the surface of the vertical alignment film when the application voltage across the liquid crystal layer is lower than the threshold voltage. In the current context, the “liquid crystal molecules being aligned vertically with respect to the surface of the vertical alignment film” indicates that the liquid crystal molecules have a pretilt angle of from 85° to 90°, both inclusive, with respect to the surface of the vertical alignment film. The pretilt angle of liquid crystal molecules refers to the angle by which the major axis of the liquid crystal molecules inclines relative to the primary face of each substrate when no voltage is being applied across the liquid crystal layer. The magnitude of the pretilt varies in particular with the combination of the alignment film or the grating layer and the liquid crystal molecules.

(51) The vertical alignment film 41 may be made of a common material that is well-known in the field of liquid crystal display panels such as a polymer including polyimide in the main chain, a polymer including polyamic acid in the main chain, or a polymer including polysiloxane in the main chain. The alignment film can be formed by applying an alignment film material by any application method such as flexo printing or inkjet coating.

(52) The grating layer 42 is provided across the entire display area 10A. The grating layer 42 has, for example, grooves that has a triangular cross-section on the surface on the liquid crystal layer 22 side. The grating layer is formed, for example, from an insulating film. The grating layer 42 is preferably transparent.

(53) Two stable alignment states, that is, a state in which the liquid crystal molecules 22A on the second substrate 200 side are vertically aligned and a state in which the liquid crystal molecules 22A on the second substrate 200 side are horizontally aligned, are obtained by optimizing, for example, the depth and interval (pitch) of the grooves when the application voltage across the liquid crystal layer 22 is lower than the threshold voltage. Furthermore, the liquid crystal molecules 22A can be switched between the alignment state shown in FIG. 6 and the alignment state shown in FIG. 8, by applying voltage pulses with different polarities across the pixel electrode 21 and the

opposite electrode **23**. These two alignment states are maintained even when no voltage pulses are applied.

(54) In the first stable state, the pretilt angle of the liquid crystal molecules **22A** on the first substrate **100** side is preferably from 85° to 90°, both inclusive, and, the pretilt angle of the liquid crystal molecules **22A** on the second substrate **200** side is preferably from 85° to 90°, both inclusive. This particular structure enables producing an even better black display.

(55) In the second stable state, the pretilt angle of the liquid crystal molecules **22A** on the first substrate **100** side is preferably from 85° to 90°, both inclusive, and the pretilt angle of the liquid crystal molecules **22A** on the second substrate **200** side is preferably from 0° to 5°, both inclusive. This particular structure enables producing an even better white display.

(56) The first support substrate **101** is, for example, a glass substrate or an insulating substrate made of a resin film of, for example, polyimide. The second support substrate **201**, facing a viewer, may be, for example, an insulating substrate made of, for example, glass or a transparent (transmissive) film.

(57) The semiconductor layer **102** is provided in the self-luminous element portion **1B**, not in the reflective liquid crystal portion **1A**. In the current context, a “member being provided in a region” indicates that the member is provided at least in a part of the region in a plan view. In addition, a “member being not provided in a region” indicates that the member is not provided at all in the region in a plan view.

(58) The semiconductor layer **102** may be made of a semiconductor often used in display devices, for example, low-temperature polycrystalline silicon (hereinafter, “LTPS”) or indium gallium zinc oxide (hereinafter, “In—Ga—Zn—O”).

(59) The source electrode **12S**, the drain electrode **12D**, and the gate electrode **12G** are provided in the self-luminous element portion **1B**, not in the reflective liquid crystal portion **1A**. The source electrode **12S**, the drain electrode **12D**, and the gate electrode **12G** may be made of, for example, a conductive layer containing either a metal such as titanium, aluminum, molybdenum, copper, or chromium or an alloy of any of these metals.

(60) The gate insulating film **103** is provided across the entire display area **10A**. In the current context, a “member being provided across an entire region” indicates that the member is provided across substantially the entire region in a plan view, except for contact holes and other like specific parts. The gate insulating film **103** is preferably an inorganic insulating film. The inorganic insulating film may be, for example, either an inorganic film such as a silicon oxide (SiO.sub.x) film, a silicon nitride (Si.sub.xN.sub.y) film, a silicon oxynitride (SiO.sub.xN.sub.y, where x>y) film, or a silicon nitroxide (SiN.sub.xO.sub.y, where x>y) film or a stack of any of these films.

(61) The inorganic insulating film **104** is provided across the entire display area **10A**. The inorganic insulating film **104** may be, for example, either an inorganic film such as a silicon oxide (SiO.sub.x) film, a silicon nitride (Si.sub.xN.sub.y) film, a silicon oxynitride (SiO.sub.xN.sub.y, where x>y) film, or a silicon nitroxide (SiN.sub.xO.sub.y, where x>y) film or a stack of any of these films.

(62) The insulating film **105** is provided across the entire display area **10A**. The insulating film **105** may be, an inorganic insulating film, an organic insulating film, or a stack of an inorganic insulating film and an organic insulating film. The inorganic insulating film may be, for example, either an inorganic film such as a silicon oxide (SiO.sub.x) film, a silicon nitride (Si.sub.xN.sub.y) film, a silicon oxynitride (SiO.sub.xN.sub.y, where x>y) film, or a silicon nitroxide (SiN.sub.xO.sub.y, where x>y) film or a stack of any of these films. The organic insulating film may be, for example, either an organic film of an acrylic resin, a polyimide resin, or a novolac resin or a stack of any of these films.

(63) The first support substrate **101** includes on a surface thereof: TFTs such as drive TFTs **11** and the current supply TFTs **12**; and wiring such as bus lines. The insulating film **105** has a function of planarizing this surface and is, for this reason, alternatively called a planarization film. The

insulating film **105** is provided for the purpose of planarizing the surface by eliminating irregularities in the surface between those parts where, for example, TFTs are provided and those parts where, for example, no TFTs are provided and is, for this reason, preferably made of an organic material such as a polyimide resin.

(64) The reflector **21X** is provided in the reflective liquid crystal portion **1A**, not in the self-luminous element portion **1B**. The reflector **21X** is provided between the insulating film **105** and the coating layer **35**. The reflector **21X** has a function of reflecting, toward the second substrate **200** side, the light incident on the second substrate **200** side and having passed through the liquid crystal layer **22**. A reflective display is performed by reflecting the incident light from the second substrate **200** side off the reflector **21X** and letting the reflected light travel through the liquid crystal layer **22**. The reflector **21X** is formed by forming a film of various high reflection metals such as Al and Ag alloys.

(65) The reflector **21X** is preferably disposed in the same layer as the first electrode **31**. The display device **1** configured in this manner allows for simultaneous formation of the reflector **21X** and the first electrode **31** and can therefore be manufactured more easily and conveniently.

(66) The pixel electrode **21** and the opposite electrode **23** are provided across the entire display area **10A**. The pixel electrode **21** and the opposite electrode **23** may be formed, for example, by forming a monolayer or multilayered film of, a transparent conductive material such as indium tin oxide (ITO), indium zinc oxide (IZO), zinc oxide (ZnO), or tin oxide (SnO) or an alloy of these materials by, for example, sputtering and thereafter patterning the monolayer or multilayered film by photolithography.

(67) The pixel electrode **21** and the opposite electrode **23** are connected to a terminal section provided in the non-display area **10B**. The passive drive of the reflective liquid crystal display element **20** is realized by controlling, through this terminal section, the voltage across the pixel electrode **21** and the opposite electrode **23**. As described here, the reflective liquid crystal display element **20** is passively driven and for this reason, does not require active elements (diodes, transistors, etc.). Signals are inputted from the terminal section provided on an end face (non-display area **10B**) of the display device **1**. Therefore, the pixel electrode **21** and the opposite electrode **23**, which are transparent electrodes, are provided in the display area **10A**, but, wiring, such as the gate bus lines and the source bus lines, for controlling the voltage across the pixel electrode **21** and the opposite electrode **23** are not provided in the display area **10A**.

(68) The color filter layer **24** is provided between the second support substrate **201** and the opposite electrode **23**. The color filter layer **24** is, for example, a red color filter, a green color filter, or a blue color filter. The red color filter, the green color filter, and the blue color filter are made of, for example, a transparent resin containing a pigment.

(69) The inclusion of the color filter layer **24** enables a color display by the reflective liquid crystal display element **20**. In contrast, a color display can be produced also on the self-luminous display element **30** side by using the color filter layer **24**. Nevertheless, when, for example, red light, green light, and blue light are emitted directly by selecting a material for the organic layer **33**, the color filter layer **24** is unnecessary on the self-luminous display element **30** side.

(70) The circular polarizer **25** refers to a polarizer that converts incident, nonpolarized light to circularly polarized light. The circular polarizer **25** includes, for example, a linear polarizer and a $\lambda/4$ retarder. Furthermore, a $\lambda/2$ retarder may be used in combination with a $\lambda/4$ retarder so as to exhibit $1/4$ wavelength conditions across a broad range of wavelengths. The $\lambda/4$ retarder includes an optical film prepared by single axis extension.

(71) The reflective liquid crystal display element **20** includes the circular polarizer **25**. This structure can achieve the following effects. The light having passed through the circular polarizer **25** is changed to, for example, right polarized light as a result of the phase of linearly polarized light being shifted by the $1/4$ wavelength. Since the initial alignment of the liquid crystal molecules **22A** is a vertical alignment, external light is passed unchanged through the liquid crystal layer **22**

and reflected off the reflector **21X** so that the polarization flips from right circular polarization to left circular polarization. Therefore, the external light having travelled in the direction opposite to the incident direction and having returned to the circular polarizer **25** forms linearly polarized light with an angle perpendicular by 90° with respect to the transmission axis of the linear polarizer and is not passed through the circular polarizer **25**, thereby producing a black display.

(72) In contrast, if a voltage that has the first pulse waveform is applied across the pixel electrode **21** and the opposite electrode **23**, and the liquid crystal molecules **22A** assume an HAN alignment, external light is further shifted in phase by the $\frac{1}{4}$ wavelength by the liquid crystal layer **22** and therefore is retarded by $\frac{1}{2}$ the wavelength upon reaching the reflector **21X**, and reflects as linearly polarized light. After being reflected, the external light follows a path opposite to the incoming path and is therefore passed through the circular polarizer **25**, thereby producing a white display.

(73) Furthermore, if a voltage that has the second pulse waveform, which differs from the first pulse waveform, is applied across the pixel electrode **21** and the opposite electrode **23**, and the liquid crystal molecules **22A** assume a vertical alignment, a black display is produced as described above.

(74) The self-luminous display element **30** includes: the first electrode **31** provided in the self-luminous element portion **1B** of **1P** of one pixel and provided on the liquid crystal layer **22** side of the insulating film **105**; the self-luminous-element-side insulating film **32** provided around the first electrode **31**; the organic layer **33** provided on the liquid crystal layer **22** side of the first electrode **31** surrounded by the self-luminous-element-side insulating film **32**; and the second electrode **34** entirely covering the self-luminous-element-side insulating film **32** and the organic layer **33** (covering the entire faces on the liquid crystal layer **22** side of the self-luminous-element-side insulating film **32** and the organic layer **33**).

(75) The first electrode **31** is, for example, formed as an anode electrode. In the present embodiment, since the display screen is viewed from the upper side in FIG. **1**, the first electrode **31** is formed as a reflective electrode and structured so as to project all the emission upward.

Therefore, its material is selected from reflective materials, depending on, for example, a relationship of a work function with, for example, the organic layer **33**, which is in contact with this first electrode **31**. The first electrode **31** is made from, for example, a stack of ITO/APC/ITO films.

(76) The self-luminous-element-side insulating film **32** is what is also called an insulating bank or a partition wall. The self-luminous-element-side insulating film **32** is formed to delimit a light-emitting region for the self-luminous display element **30** and also to prevent the first electrode **31** and the second electrode **34** from coming into contact with each other and hence being short-circuited. The organic layer **33** is stacked on the first electrode **31** surrounded by the self-luminous-element-side insulating film **32**. The self-luminous-element-side insulating film **32** is made of, for example, a resin such as polyimide or an acrylic resin.

(77) The organic layer **33** is stacked on the liquid crystal layer **22** side of the exposed, first electrode **31** surrounded by the self-luminous-element-side insulating film **32**. This organic layer **33** is shown as a single layer in FIG. **1**, but includes a plurality of stacked layers of various materials. In addition, this organic layer **33** is weak to moisture and cannot be patterned after being formed across the entire face. Therefore, the organic layer **33** is formed by selectively vapor-depositing a vaporized or sublimated organic material only to required portions by using a vapor deposition mask.

(78) Specifically, the organic layer **33** includes, for example, as a layer in contact with the first electrode (anode electrode) **31**, a hole injection layer composed of a material that exhibits good ionization energy matching for improving hole injection. The organic layer **33** includes, on the liquid crystal layer **22** side of this hole injection layer, a hole transport layer that can improve the stable transport of holes and that can confine electrons inside the light-emitting layer (energy barrier). This hole transport layer is made of, for example, an amine-based material. Furthermore, the organic layer **33** includes a light-emitting layer selected in accordance with an emission

wavelength on the liquid crystal layer **22** side of the hole transport layer. The light-emitting layer is formed by, for example, doping Alq.sub.3 with a red or green organic fluorescent material for the red and green colors. In addition, a DSA-based organic material is used as a blue material. In contrast, when coloring is done using the color filter layer **24**, all the light-emitting layers may be made of the same material without doping. The organic layer **33** further includes, on the liquid crystal layer **22** side of light-emitting layer, an electron transport layer that improves electron injection and that stably transports electrons. The electron transport layer is formed of, for example, Alq.sub.3. The stack of films in the organic layer **33** is formed by stacking these layers each to a thickness of approximately a few tens of nanometers. Note that between the organic layer **33** and the second electrode **34**, there may be provided, for example, a LiF and/or Liq electron injection layer that improves electron injection. In the present embodiment, the organic layer **33** may include these organic and inorganic layers.

(79) As described earlier, for the light-emitting layer in the stack of films in the organic layer **33**, an organic layer of a material in accordance with each of the RGB colors may be deposited. In the example shown in FIG. **1**, the light-emitting layers are formed of the same organic material, and the color of emitted light is specified by the color filter layer **24**. In addition, for example, the hole transport layer and the electron transport layer are preferably separately deposited using a material suited to the light-emitting layer in view of better light emission performance. However, there are cases where these hole and electron transport layers are stacked using the same material that is common to two or three of the RGB colors in consideration of material cost.

(80) After the stack of films in the organic layer **33** including, for example, an electron injection layer such as a LiF layer is completely formed, the second electrode **34** is formed on the liquid crystal layer **22** side of the self-luminous-element-side insulating film **32** and the organic layer **33**. The second electrode **34** needs to be completely covered with the coating layer **35** because the second electrode **34** is made of a transparent material, for example, a thin Mg—Ag eutectic crystal film and for this reason, susceptible to corrosion in moisture.

(81) The self-luminous display element **30** is formed in the self-luminous element portion **1B** as described above. For example, the liquid crystal layer **22** and the opposite electrode **23** are provided also on the self-luminous display element **30** as shown in FIG. **1** because as described earlier, it is difficult to provide the liquid crystal layer **22** only in the reflective liquid crystal portion **1A**. However, the pixel electrode **21** is not disposed in the self-luminous element portion **1B**. Therefore, in the self-luminous element portion **1B**, the same state occurs as in the case where the voltage applied across the pixel electrode **21** and the opposite electrode **23** is lower than a threshold value. In other words, although normally black is achieved for external light, the light emitted by the self-luminous display element **30** is the same as in the absence of the liquid crystal layer **22** because the liquid crystal layer **22** is in a vertical alignment, and that light passes through the circular polarizer **25** with no changes at all. Then, since the light having passed through the circular polarizer **25** is visually recognized as is, the image displayed by the emission of light by the self-luminous display element **30** is visually recognized as is from the observation side.

(82) Note that the light emitted by the self-luminous display element **30** decays to appropriately half in the circular polarizer as the light passed through the circular polarizer **25**. However, the circular polarizer **25** is preferably disposed also on the self-luminous element portion **1B** for the following reasons. When external light enters through the front face, since the first electrode **31** in the self-luminous display element **30** is made of a light-reflective material as described earlier, the display screen becomes highly difficult to visually recognize if the light incident on the front face is reflected, for example, off the first electrode **31** in the self-luminous display element **30** and exits to the outside. However, if the circular polarizer **25** is provided, since the rotation direction of circularly polarized light is reversed upon being reflected off, for example, the first electrode **31** as described earlier, the reflected light cannot pass through the circular polarizer. As a result, the reflected light can be cut off. Although the self-luminous display element **30** is not activated when

there is much external light, since even when the reflective liquid crystal display element **20** is activated, reflected light is generated regardless of whether the self-luminous display element **30** is being in operation, the visual recognizability of the display device **1** significantly decreases even when the reflective liquid crystal display element **20** is being in operation if the circular polarizer **25** is not provided in the self-luminous element portion **1B**.

(83) The coating layer **35** is alternatively referred to as a sealing layer or a thin film sealant (TFE: thin film encapsulation). The coating layer **35** is preferably an inorganic insulating film. Examples of the coating layer **35** include inorganic insulating films such as a silicon nitride film and a silicon oxide film. The coating layer **35** may be either a single layer or a stack of two or more layers.

(84) The coating layer **35** is provided contiguously across the reflective liquid crystal portion **1A** and the self-luminous element portion **1B**. This structure enables restraining the degradation of the self-luminous display element **30**. In the current context, a “member being provided contiguously across two regions” indicates that the member is provided across each of the two regions and also seamlessly from one of the two regions to the other in a plan view. The coating layer **35** is provided entirely across each of the reflective liquid crystal portion **1A** and the self-luminous element portion **1B** and also seamlessly from the reflective liquid crystal portion **1A** to the self-luminous element portion **1B** in a plan view.

(85) The coating layer **35** is preferably provided contiguously across the plurality of pixels **1P**. This structure enables further restraining the penetration of, for example, water through the boundary in the coating layer **35**, thereby enabling further restraining the degradation of the self-luminous display element **30**. The coating layer **35** is provided entirely across each of the plurality of pixels **1P** and also seamlessly between the plurality of pixels **1P** in a plan view.

(86) A circuit for driving the self-luminous display element **30** is structured, for example, as in the equivalent circuit diagram in FIG. **3**. In other words, a horizontal row of pixels can be selected by connecting the gate electrodes of the drive TFTs **11** to a gate bus line **15** and applying a gate signal (select signal) to the gate bus line **15**. In addition, the source electrodes of the drive TFTs **11** are connected to a source bus line **14**, so that a vertical column of pixels is ready for data signal inputs. Then, only the pixels where the gate bus line **15** provided with the select signal intersects with the source bus line **14** provided with the data signal is configured to be able to display on the basis of the provided data signal. The drive TFT **11** has a drain electrode thereof connected to the gate electrode **12G** of the current supply TFT **12** to control the electric current flowing through the self-luminous display element **30** in response to display information. The drain electrode **12D** of the current supply TFT **12** is connected to a current bus line **16**, and the source electrode **12S** thereof is connected to the first electrode **31** (anode electrode) of the self-luminous display element **30**. The second electrode **34** (cathode electrode) of the self-luminous display element **30** is connected to a cathode bus line **17** through contact holes **17c1** and **17c2**. This structure enables driving the self-luminous display element **30** provided in the self-luminous element portion **1B**.

(87) When the drive TFT **11** is on, an image is displayed by the self-luminous display element **30** by controlling the voltage for the pixel electrode **21** and the opposite electrode **23** so that a voltage that is lower than a threshold value is applied across the pixel electrode **21** and the opposite electrode **23** and also turning on the current supply TFT **12** using the drive TFT **11**. In contrast, when the drive TFT **11** is off, no image is displayed by the self-luminous display element **30** by applying a voltage higher than or equal to the threshold value across the pixel electrode **21** and the opposite electrode **23** and also turning off the current supply TFT **12** using the drive TFT **11**. An image can be appropriately displayed by turning off/on the image display produced by the reflective liquid crystal display element **20** in synchronism with the turning on/off of the image display produced by the self-luminous display element **30**.

Embodiment 2

(88) The present embodiment will focus on features that are unique to the present embodiment, and description of the content that is common to the present embodiment and Embodiment 1 above is

omitted. The present embodiment is substantially the same as Embodiment 1, except for the structure of the alignment film disposed between the first substrate **100** and the liquid crystal layer **22**.

(89) FIG. **10** is a schematic cross-sectional view of a pixel in a display device in accordance with Embodiment 2. FIG. **11** is a schematic cross-sectional view of liquid crystal molecules in the display device in accordance with Embodiment 2 in a TN alignment. FIG. **12** is a diagram representing a first pulse waveform of a voltage applied across a pixel electrode and an opposite electrode in the display device in accordance with Embodiment 2. FIG. **13** is a schematic cross-sectional view of liquid crystal molecules in the display device in accordance with Embodiment 2 in an HAN alignment. FIG. **14** is a diagram representing a second pulse waveform of the voltage applied across the pixel electrode and the opposite electrode in the display device in accordance with Embodiment 2. FIG. **11** shows the initial alignment state, in other words, the first stable state. FIG. **13** shows the second stable state.

(90) The display device **1** in accordance with the present embodiment includes: a pretilted horizontal alignment film **43** disposed between the first substrate **100** and the liquid crystal layer **22**; and a grating layer **42** disposed between the second substrate **200** and the liquid crystal layer **22**. The liquid crystal layer **22** assumes either one of the first stable state in which the liquid crystal molecules **22A** are in a TN (twisted nematic) alignment and the second stable state in which the liquid crystal molecules **22A** are in the HAN alignment in the absence of applied voltage where a voltage that is lower than a threshold value is applied across the pixel electrode **21** and the opposite electrode **23**. The liquid crystal molecules **22A** are switched between the first stable state and the second stable state by applying a pulsed voltage across the pixel electrode **21** and the opposite electrode **23**. The initial alignment of the liquid crystal molecules **22A** in accordance with the present embodiment is a TN alignment. In the present embodiment, the circular polarizer **25** is set up so that the display device **1** can produce a black display in the first stable state (TN alignment). In the present embodiment, the display device **1** produces a white display in the second stable state (HAN alignment). This bistable liquid crystal display mode is alternatively referred to as ZBD.

(91) The pretilted horizontal alignment film **43** is provided across the entire display area **10A**. The pretilted horizontal alignment film **43** has a function of orienting the liquid crystal molecules **22A** in the liquid crystal layer **22** to an angle of from 0° exclusive to 10° inclusive with respect to the surface of the horizontal alignment film **43** in the absence of applied voltage. The pretilted horizontal alignment film **43** preferably has a function of orienting the liquid crystal molecules **22A** in the liquid crystal layer **22** to an angle of from 3° to 5° , both inclusive, with respect to the surface of the horizontal alignment film **43** in the absence of applied voltage. This structure can render the initial alignment a TN alignment.

(92) The pretilted horizontal alignment film **43** may be made of a common material in the field of liquid crystal display panels such as a polymer including polyimide in the main chain, a polymer including polyamic acid in the main chain, or a polymer including polysiloxane in the main chain.

(93) The pretilted horizontal alignment film **43** is obtained, for example, by forming a film of an alignment film material containing a rubbing alignment film polymer on a substrate, rotating a roller around which a piece of cloth composed of, for example, rayon or cotton is wound while maintaining a constant rotational speed and a constant distance separating the roller from the substrate, and rubbing the surface of the film containing the rubbing alignment film polymer in a prescribed direction. The pretilted horizontal alignment film **43** is obtained, for example, by performing a rubbing process on the film surface of the alignment film. The rubbing process may be done from the far side toward the near side of the drawing (FIG. **10**).

(94) In the first stable state, the liquid crystal molecules **22A** are in a TN alignment between the pretilted horizontal alignment film **43** disposed on the first substrate **100** side and the grating layer **42** disposed on the second substrate **200** side as shown in FIG. **11**. At this stage, by applying the pulsed voltage shown in FIG. **12** across the pixel electrode **21** on the first substrate **100** side and the

opposite electrode **23** on the second substrate **200** side, the liquid crystal molecules **22A** on the grating layer **42** side are released from anchoring and rotated. The rotated liquid crystal molecules **22A** are realigned to the second stable state, assuming the HAN alignment shown in FIG. **13**.
(95) In the HAN alignment state shown in FIG. **13**, by applying the pulsed voltage shown in FIG. **14** across the pixel electrode **21** and the opposite electrode **23**, the liquid crystal molecules **22A** on the grating layer **42** side are released from anchoring and rotated. The rotated liquid crystal molecules **22A** are realigned to the first stable state, assuming the TN alignment shown in FIG. **11**.
(96) Although there is a need to apply a pulsed voltage for switching between the first stable state shown in FIG. **11** and the second stable state shown in FIG. **13**, there is no need to continuously apply the voltage across the pixel electrode **21** and the opposite electrode **23** to maintain the two stable states because both the first stable state and the second stable state are energetically stable states.

(97) In the first stable state, the pretilt angle of the liquid crystal molecules **22A** on the first substrate **100** side is preferably from 3° to 5° , both inclusive, the pretilt angle of the liquid crystal molecules **22A** on the second substrate **200** side is preferably from 0° to 5° , both inclusive, and the alignment direction of the liquid crystal molecules **22A** on the first substrate **100** side and the alignment direction of the liquid crystal molecules **22A** on the second substrate **200** side preferably make an angle of from 80° to 90° , both inclusive, in a plan view. This structure enables producing a better black display.

(98) In the second stable state, the pretilt angle of the liquid crystal molecules **22A** on the first substrate **100** side is preferably from 3° to 5° , both inclusive, and the pretilt angle of the liquid crystal molecules **22A** on the second substrate **200** side is preferably from 85° to 90° , both inclusive. This structure enables producing a better white display.

Embodiment 3

(99) The present embodiment will focus on features that are unique to the present embodiment, and description of the content that is common to the present embodiment and Embodiment 1 above is omitted. The present embodiment is substantially the same as Embodiment 1, except for the structure of the alignment film disposed between the first substrate **100** and the liquid crystal layer **22**, the provision of an alignment film in place of the grating layer between the second substrate **200** and the liquid crystal layer **22**, and the use of a linear polarizer in place of the circular polarizer **25**.

(100) FIG. **15** is a schematic cross-sectional view of a pixel in a display device in accordance with Embodiment 3. FIG. **16** is a schematic cross-sectional view of liquid crystal molecules in the display device in accordance with Embodiment 3 in a homogeneous alignment. FIG. **17** is a diagram representing a first pulse waveform of a voltage applied across a pixel electrode and an opposite electrode in the display device in accordance with Embodiment 3. FIG. **18** is a schematic cross-sectional view of liquid crystal molecules in the display device in accordance with Embodiment 3 in a twisted alignment. FIG. **19** is a diagram representing a second pulse waveform of the voltage applied across the pixel electrode and the opposite electrode in the display device in accordance with Embodiment 3. FIG. **16** shows the initial alignment state, in other words, the first stable state. FIG. **18** shows the second stable state.

(101) The display device **1** in accordance with the present embodiment includes: a weak anchoring alignment film **44** disposed between the first substrate **100** and the liquid crystal layer **22**; and a strong anchoring alignment film **45** disposed between the second substrate **200** and the liquid crystal layer **22**, as shown in FIG. **15**. The liquid crystal layer **22** assumes either one of the first stable state in which the liquid crystal molecules **22A** are in a homogeneous alignment and the second stable state in which the liquid crystal molecules **22A** on the first substrate **100** side assume a twisted alignment that is rotated by 180° from the first stable state in a plan view, in the absence of applied voltage where a voltage that is lower than a threshold value is applied across the pixel electrode **21** and the opposite electrode **23**. The liquid crystal molecules **22A** are switched between

the first stable state and the second stable state by applying a pulsed voltage across the pixel electrode **21** and the opposite electrode **23**. The initial alignment of the liquid crystal molecules **22A** in accordance with the present embodiment is a homogeneous alignment. In the present embodiment, the circular polarizer **25** is set up so that the display device **1** can produce a black display in the first stable state (homogeneous alignment). In the present embodiment, the display device **1** produces a white display in the second stable state (twisted alignment). This bistable liquid crystal display mode is referred to as BiNem.

(102) The liquid crystal layer **22** may have a cell gap specified to, for example, 2 μm .

(103) The weak anchoring alignment film **44** and the strong anchoring alignment film **45** are provided across the entire display area **10A**. The weak anchoring alignment film **44** and the strong anchoring alignment film **45** are, for example, rubbing alignment films, and the anchoring strength can be specified to a desirable range by changing rubbing strength. The weak anchoring alignment film **44** is an alignment film with a lower anchoring energy than the strong anchoring alignment film **45**.

(104) In the first stable state, the liquid crystal molecules **22A** are homogeneously aligned between the weak anchoring alignment film **44** disposed on the first substrate **100** side and the strong anchoring alignment film **45** disposed on the second substrate **200** side as shown in FIG. **16**. At this stage, by applying the pulsed voltage shown in FIG. **17** across the pixel electrode **21** on the first substrate **100** side and the opposite electrode **23** on the second substrate **200** side, the liquid crystal molecules **22A** on the first substrate **100** side are released from anchoring and rotated by 180° from the first stable state in a plan view. In contrast, the alignment direction of the liquid crystal molecules **22A** on the second substrate **200** side does not change. The rotation of the liquid crystal molecules **22A** on the first substrate **100** side propagates toward the second substrate **200** side and rotates the liquid crystal molecules **22A**. The rotated liquid crystal molecules **22A** are realigned to the second stable state, assuming the twisted alignment shown in FIG. **18**.

(105) In the twisted alignment shown in FIG. **18**, if the pulsed voltage shown in FIG. **19** is applied across the pixel electrode **21** and the opposite electrode **23**, the liquid crystal molecules **22A** on the first substrate **100** side are released from anchoring and rotated. The rotated liquid crystal molecules **22A** are realigned to the first stable state, assuming the homogeneous alignment shown in FIG. **16**.

(106) Although there is a need to apply a pulsed voltage for switching between the first stable state shown in FIG. **16** and the second stable state shown in FIG. **18**, there is no need to continuously apply a voltage across the pixel electrode **21** and the opposite electrode **23** to maintain the two stable states because both the first stable state and the second stable state are energetically stable states.

(107) In the first stable state, the pretilt angle of the liquid crystal molecules **22A** on the first substrate **100** side is preferably from 0° to 5° , both inclusive, the pretilt angle of the liquid crystal molecules **22A** on the second substrate **200** side is preferably from 5° to 10° , both inclusive, and the alignment direction of the liquid crystal molecules **22A** on the first substrate **100** side and the alignment direction of the liquid crystal molecules **22A** on the second substrate **200** side preferably make an angle of from 0° to 10° , both inclusive, in a plan view. This structure enables producing a better black display.

(108) In the second stable state, the pretilt angle of the liquid crystal molecules **22A** on the first substrate **100** side is preferably from 0° to 5° , both inclusive, the pretilt angle of the liquid crystal molecules **22A** on the second substrate **200** side is preferably from 5° to 10° , both inclusive, the alignment direction of the liquid crystal molecules **22A** on the first substrate **100** side and the alignment direction of the liquid crystal molecules **22A** on the second substrate **200** side preferably make an angle of from 0° to 10° , both inclusive, in a plan view, and the liquid crystal molecules **22A** are preferably twisted in-plane by from 170° to 180° , both inclusive, from the first substrate **100** side toward the second substrate **200** side. This structure enables producing a better white

display.

Embodiment 4

(109) The present embodiment will focus on features that are unique to the present embodiment, and description of the content that is common to the present embodiment and Embodiment 1 above is omitted. The present embodiment is substantially the same as Embodiment 1, except for the structure of the reflector **21X**.

(110) FIG. **20** is a schematic cross-sectional view of a pixel in a display device in accordance with Embodiment 4. Referring to FIG. **20**, the reflector **21X** in the display device **1** in accordance with the present embodiment has projections and depressions on a surface thereof on the liquid crystal layer **22** side. This structure diffuses reflected light in all directions, thereby improving visibility and reflectivity.

(111) The reflector **21X** has a surface structure with fine projections and depressions (MRS: micro reflective structure). The reflector **21X** with the MRS shape is obtained, for example, by forming projections and depressions on the surface of the insulating film **105** on the liquid crystal layer **22** side by photolithography and forming a film of, for example, various high reflection metals such as Al and an Ag alloy. The MRS shape can scatter external light in a certain range of angles. Therefore, ambient light can be efficiently utilized, thereby producing a bright reflective display.

Claims

1. A display device comprising: a first substrate including a switching element; a liquid crystal layer containing liquid crystal molecules; and a second substrate including an opposite electrode, the first substrate, the liquid crystal layer and the second substrate are provided sequentially, the display device further comprising a plurality of pixels arranged in a matrix in a display area, wherein each of the plurality of pixels includes a reflective liquid crystal portion and a self-luminous element portion, in the reflective liquid crystal portion, the first substrate includes a reflector, a coating layer, and a pixel electrode, which are provided sequentially toward a side of the liquid crystal layer, but does not include a switching element, the reflector, the pixel electrode, the liquid crystal layer, and the opposite electrode form a reflective liquid crystal display element that operates in bistable liquid crystal display mode, in the self-luminous element portion, the first substrate includes: the switching element; a self-luminous display element including a first electrode, an organic layer, and a second electrode; and the coating layer disposed on a side of the liquid crystal layer of the self-luminous display element, and the coating layer is provided contiguously across the reflective liquid crystal portion and the self-luminous element portion.
2. The display device according to claim 1, further comprising: a non-display area provided around the display area; and a wire provided in the non-display area of the first substrate, wherein in the non-display area, the opposite electrode is connected to the wire, and the pixel electrode is connected to the wire.
3. The display device according to claim 1, wherein the liquid crystal layer assumes either one of a first stable state and a second stable state in which the liquid crystal molecules assume different alignment states in absence of applied voltage where a voltage that is lower than a threshold value is applied across the pixel electrode and the opposite electrode, and the liquid crystal molecules are switched between the first stable state and the second stable state by applying a pulsed voltage across the pixel electrode and the opposite electrode.
4. The display device according to claim 1, wherein the coating layer is provided contiguously across the plurality of pixels.
5. The display device according to claim 1, wherein the reflector is disposed in a same layer as the first electrode.
6. The display device according to claim 1, further comprising: a vertical alignment film disposed between the first substrate and the liquid crystal layer; and a grating layer disposed between the

second substrate and the liquid crystal layer, wherein the liquid crystal layer assumes either one of a first stable state in which the liquid crystal molecules assume a vertical alignment and a second stable state in which the liquid crystal molecules assume an HAN alignment in absence of applied voltage where a voltage that is lower than a threshold value is applied across the pixel electrode and the opposite electrode, and the liquid crystal molecules are switched between the first stable state and the second stable state by applying a pulsed voltage across the pixel electrode and the opposite electrode.

7. The display device according to claim 6, wherein in the first stable state, the liquid crystal molecules have a pretilt angle of from 85° to 90° , both inclusive, on a side of the first substrate and a pretilt angle of from 85° to 90° , both inclusive, on a side of the second substrate.

8. The display device according to claim 6, wherein in the second stable state, the liquid crystal molecules have a pretilt angle of from 85° to 90° , both inclusive, on a side of the first substrate and a pretilt angle of from 0° to 5° , both inclusive, on a side of the second substrate.

9. The display device according to claim 1, further comprising: a pretilted horizontal alignment film disposed between the first substrate and the liquid crystal layer; and a grating layer disposed between the second substrate and the liquid crystal layer, wherein the liquid crystal layer assumes either one of a first stable state in which the liquid crystal molecules assume a TN alignment and a second stable state in which the liquid crystal molecules assume an HAN alignment in absence of applied voltage where a voltage that is lower than a threshold value is applied across the pixel electrode and the opposite electrode, and the liquid crystal molecules are switched between the first stable state and the second stable state by applying a pulsed voltage across the pixel electrode and the opposite electrode.

10. The display device according to claim 9, wherein in the first stable state, the liquid crystal molecules have a pretilt angle of from 3° to 5° , both inclusive, on a side of the first substrate and a pretilt angle of from 0° to 5° , both inclusive, on a side of the second substrate, and an alignment direction of the liquid crystal molecules on the side of the first substrate and an alignment direction of the liquid crystal molecules on the side of the second substrate make an angle of from 80° to 90° , both inclusive, in a plan view.

11. The display device according to claim 9, wherein in the second stable state, the liquid crystal molecules have a pretilt angle of from 3° to 5° , both inclusive, on a side of the first substrate and a pretilt angle of from 85° to 90° , both inclusive, on a side of the second substrate.

12. The display device according to claim 1, further comprising: a weak anchoring alignment film disposed between the first substrate and the liquid crystal layer; and a strong anchoring alignment film disposed between the second substrate and the liquid crystal layer, wherein the liquid crystal layer assumes either one of a first stable state in which the liquid crystal molecules assume a homogeneous alignment and a second stable state in which the liquid crystal molecules on a side of the first substrate assume a twisted alignment in which these liquid crystal molecules are twisted by 180° from the first stable state in a plan view, in absence of applied voltage where a voltage that is lower than a threshold value is applied across the pixel electrode and the opposite electrode, and the liquid crystal molecules are switched between the first stable state and the second stable state by applying a pulsed voltage across the pixel electrode and the opposite electrode.

13. The display device according to claim 12, wherein in the first stable state, the liquid crystal molecules have a pretilt angle of from 0° to 5° , both inclusive, on the first substrate and a pretilt angle of from 5° to 10° , both inclusive, on a side of the second substrate, and an alignment direction of the liquid crystal molecules on the side of the first substrate and an alignment direction of the liquid crystal molecules on the side of the second substrate make an angle of from 0° to 10° , both inclusive, in a plan view.

14. The display device according to claim 12, wherein in the second stable state, the liquid crystal molecules have a pretilt angle of from 0° to 5° , both inclusive, on the side of the first substrate and a pretilt angle of from 5° to 10° , both inclusive, on a side of the second substrate, an alignment

direction of the liquid crystal molecules on the side of the first substrate and an alignment direction of the liquid crystal molecules on the side of the second substrate make an angle of from 0° to 10° , both inclusive, in a plan view, and the liquid crystal molecules are aligned twisted in-plane by from 170° to 180° , both inclusive, from the side of the first substrate toward the second substrate.

15. The display device according to claim 1, wherein the reflector has projections and depressions on a surface of the reflector on a side of the liquid crystal layer.
